ESSAYS

ON THE

APPLIED PHYSIOLOGY

OF

THE NOSE

BY

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TO THE MEMORY

OF

JONATHAN WRIGHT

PREFACE

This book is presented to the profession in all humility. It is written by a rhinologist for rhinologists with the ardent hope that the author's sympathetic understanding of the requirements in this field may partially compensate for his limitations as a physiologist.

As an examiner of the Board of Otolaryngology since its inception, the author has had occasion to watch the interest in pathology grow from nothing to its present satisfactory status. During the same period the physiology has remained in a state of suspended animation, due no doubt to the fact that its literature has been all but inaccessible to clinicians.

This and the efforts required in exhuming material for lectures to graduate students in the Medical School and in other courses over the country, have brought out pointedly the need of a comprehensive and reliable text.

No such work has thus far existed. In the preparation of the present volume it has been necessary to comb the literature, to talk with colleagues in and out of rhinology, and sometimes to conduct one's own experiments in order to round out the material or to be able to select from among diverse opinions those which seem most likely to approach the truth.

To the authors of these publications, or to their memories, to the many friends who have taken the time to express their views and recount their observations, and to the students whose pertinent and often confounding questions have prodded his flagging typewriter, this author does homage.

Particularly does he wish to give thanks to Dr. L. W. Dean, who as head of the Department of Otolaryngology in Washington University has kept laboratories at his disposal, and whose awareness has resulted in the emphasis which the physiological phases have received in all the deliberations of that Department.

To his friends, Dr. Anderson Hilding, Dr. J. Parsons Schaeffer, Dr. P. F. Swindle and Dr. Alfred Lucas, he is indebted both for the unlimited use of their exceptional material and for their stimulating conversations.

He further acknowledges a debt to Dr. Joseph Erlanger, Dr. Lester White and Dr. A. S. Gilson, Jr. of the Department of Physiology, and to Dr. E. V. Cowdry of the Department of Anatomy and Cytology in Washington University who have kindly given their counsel upon questions of fundamental physiology and cytology; also to Miss Esther Schroepfer for her capable assistance in the preparation of the manuscript, and to the authors and publishers of the many sources specifically mentioned in the footnotes.

ARTHUR PROETZ.

May 1941.

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INTRODUCTION

For years I waited for someone to write a book about physiology and rhinology applying them, one to the other, with a view to rationalizing clinical procedure upon a more factual basis. As time passed it became increasingly apparent that if I wanted to read such a book in my lifetime, I would have to write it.

I was never under the delusion that the impulse and the decision to do so constituted anything more than the motive force to sustain one through a seemingly interminable tussle with the library, the laboratory and the constant dismay at one's own inadequacy.

To do the subject full justice one should have, beside a lifetime of clinical experience, a firm grounding in general physiology. For the second I am compelled to substitute only an absorbing interest which has been fed upon experiment and the reading incident to the preparation of a great many lectures. The heartening receptiveness evinced by the students attending these courses, and their clamor for references and supplementary reading have supplied the incentive to amplify these lectures and put them between covers.

If there be any physiologist who feels that in so doing I have trespassed upon his domain, and have waded beyond my depth, I have no quarrel with him, but only submit that had he written the book for me I should never have thought of attempting it myself.

In attacking the problem the first consideration was naturally the scope of the presentation, and the form which it should

take: Should it be elementary, or technical, or both? Should it be encyclopedic or brief and wholly practical?

Since there are two groups of readers to whom the theme is specially directed, namely graduate students and practicing rhinologists, and since the purpose in writing a book is to get it read by those for whom it is intended, everything has finally been put down with the requirements of these two in mind.

Next I have sought to make a point of accuracy and comprehensiveness. Original sources have been consulted wherever possible, and the excerpts have been completely documented. I have tried not to fling to the reader statements against which his reason, rightly or wrongly, rebels leaving him to flounder in miserable skepticism, without benefit of reference.

The student is urged to avail himself of this bibliography. Not only will he find it a pleasant occupation to peruse the important contributions in the original, but he will avoid the paraphrasing and translation which so commonly detract from the parent thought, or possibly even misinterpret it.

Owing to the multiplicity of titles only direct references will be found in the footnotes; some additional publications, selected for their value as collateral reading, are listed at the end of each chapter.

In several instances one has had to be content with the summation of theories in the absence of facts, for many a hiatus exists even today in our comprehension of the nasal functions.

In the belief that it should be the part of the trained mind to familiarize itself with the little understood phases of its

subject if it is to make any contributions of its own, space has not been denied to the speculative and the hypothetical, provided that they have roots somewhere in the ground of scientific observation. Under such circumstances I have permitted myself at times to inject my own impressions for the consideration of the reader—for whatever they may be worth.

It is nigh impossible in this subject to avoid repetition under various headings, and not always desirable. To do so would only compel the reader to turn back and interrupt his thought, and would detract greatly from the book as a reference work.

Some very elementary matter has also been retained. If the reader finds passages which seem unnecessarily so, I apologize to him, with the reservation, however, that they were prompted by students' questions. Preparatory training is variable today, and what seems fairly patent to one student may well puzzle another.

Some attempt is made to convey in the presentation the degree of acceptance accorded to theories as this is reflected in the literature. Sometimes one has been obliged simply to state his own position, and thus risk the criticism of colleagues, for the sake of mere clarity. This has been confined to questions of minor importance, and a bibliography is always appended.

There is a very special quality of satisfaction to be derived from a first-hand acquaintance with the experimental background of our daily clinical procedure. For this reason experimental work has been emphasized in the text, and an appendix has been added, outlining a few simple procedures which the student may follow as an accompaniment to a course of lectures. They require only the materials to be found in any laboratory.

JONATHAN WRIGHT, M.D.
1860-1928

This book emanates from such a lecture course, and the sequence followed in the classroom has been retained. The drawings constitute the accompanying blackboard sketches and the photographs and motion picture strips are part of the teaching material.

Something deeper than the simple expression of esteem and affection for my old friend has prompted me to dedicate it to

the memory of Jonathan Wright. Esteem and affection I have for him, and reverence, but scarcely a page is here which does not somehow reflect the influence of his vital concern with the structures and forces of nature, and it is my wish that this tribute may discharge, though in a small measure, my very great debt to him.

The voluminous writings of Jonathan Wright, medical, philosophical and historical, constitute only part of the ferment with which he animated his friends and contemporaries. Personal contacts with him were inspiring and illuminating, not to say aggravating; a day spent with him was always a day to be remembered.

Sluder, at one point in his career found himself perplexed by the pathological implications of some of his favorite sinus specimens. He wrote to Jonathan Wright, whom at that time he did not know, asking for permission to call upon him and discuss his problems. Wright, already retired from active practice, had his mind on some historical business, and wrote Sluder not to come. Sluder went anyway, and his visit proved to be the beginning of a warm friendship which endured as long as they both lived. It resulted in Wright's contributing a prefatory chapter to Sluder's book, and subsequently in my own meeting with this remarkable man.

Wright was then living on his estate near Pleasantville, New York. Though well up in years his black eyes gave warning of the keen mind behind them. They sparkled as he talked.

My visits invariably began with a tramp about the grounds, and as invariably ended in the library (erstwhile carriage-house) in a litter of reprints, manuscripts and correspondence

from the files in the rafters. The ride back to New York only partly stilled the resulting mental vertigo, which culminated as a rule in some feverish laboratory experiment.

The problems of those days are still largely the problems of this book and so it seems entirely fitting that the face of my old friend and mentor should be peering out from its pages.

APPLIED PHYSIOLOGY OF THE NOSE

CHAPTER I

THE FUNCTIONS OF THE NOSE

THE SENSE OF SMELL—AN AIRWAY—PROTECTION OF THE LUNG—SELF CLEANSING AND PROTECTION—MOISTENING—HEATING—FUNCTIONS OF THE SINUSES—VESTIGEAL OLFACTORY ORGANS — VOCAL RESONATORS—STRUCTURAL LIGHTNESS—MOISTENING AND HEATING—INSULATION.

The functions of the nose are manifold as may well be expected of an organ which serves to prepare for use the breath of life. The nose has, from the beginning, served as something more than a mere passage for oxygen, although this in itself is of prime importance. Obviously the alimentary orifice has functions of its own, which are not compatible with the passage of air and therefore render this opening, at times, unfit for breathing. Indeed, one may wonder by what vagary of nature the airway and the foodway were united at all. The most plausible conclusion is that the availability of the mouth as an emergency airway outweighs the possible dangers of choking and infection to which it subjects the respiratory tract.

THE SENSE OF SMELL. The upper airway had early to do with the special sense of smell. Following the primitive tactile impressions common to all animate creatures, the com-

bined senses of smell and taste were the first to develop. These two senses, both recording the minutest chemical change in the environment, were essential, first to the nutrition of the animal, and second to its safety. They were at once an aid in the detection and distinction of substances necessary, beneficial and pleasurable, and a danger signal against others undesirable, poisonous or simply unpleasant.

That the qualities of pleasantness or unpleasantness are merely the final expression of what was originally experienced to be beneficial or harmful, is beyond doubt. All animals are attracted or repelled by various odors which are certainly not demonstrably advantageous or injurious to them, although relationships can be traced between usefulness and mere pleasantness. Dogs and most wild animals, for example, react acutely to animal odors and find them pleasant, although they are indifferent to perfumes and flower odors, which have no practical value and therefore no important associations.

It remains for man with his infinitely complex network of memories and associations, to concoct and elaborate for himself perfumes and aromas calculated to arouse more or less abstract images according to his individual experience.

Since in the complexity of our modern existence we have developed sight and hearing to protect us more quickly and certainly against the dangers which surround us, our olfactory sense has fallen largely into disuse, and we have become "microsmatic" animals. No longer do we recognize our friends, enemies or surroundings by their specific odors. It is only in an emergency that olfactory impressions—the house burning, the gas leaking, the toast charring—actually result in the sharp reactions customarily following visual and auditory stimuli.

In the absence of one of the readier senses, especially sight, the olfactory function comes to the rescue. This is even more pronounced when two of the other senses fail. It is well known that persons at once blind and deaf may arrive at a fairly accurate estimate of their surroundings through faint olfactory impressions which pass unnoticed by the normal individual.

Since the olfactory sense has become of secondary importance, it is seldom given more than passing notice. Though it received considerable attention in the latter half of the 19th century,[1] little that was written has survived, and the sum of our accurate knowledge of the subject would not fill a small book.

AN AIRWAY. There are several reasons why the breathing function cannot and should not be taken over by the mouth. One very obvious one is that using a common orifice would subject the respiratory tract to foreign bodies inspired while eating. Many animals require for their safety to sniff the wind for food and to detect the approach of enemies while feeding. Not only is it difficult for some species to substitute the mouth for the nose in respiration but, in others it is quite impossible. They will suffocate if the nostrils are obstructed, and will not breathe through the mouth.

The nose is the natural respiratory pathway in man and the impulse to nasal breathing is instinctive. If a nasal obstruction exists in the new-born it may be necessary to establish an airway by the insertion of a rubber tube in order to save the

1. Bawden, H.: A Bibliography of the Literature on the Organ and Sense of Smell. Jour. of Compar. Neurol., 11:1, 1901.

life of the infant.[2] Mouth-breathing must be acquired and is not found within the first two weeks of life.

VanGilse had an opportunity of studying a new-born child with a bilateral choanal atresia.[3] From his observations upon this patient he concludes that an infant cannot breathe quietly through the mouth, even when it is more or less open, as the tongue acts partially as a one-way valve. Only when the child cries is there any oral inspiration. In VanGilse's case of complete obstruction, breathing was impossible during sleep, and forced respiration was required.

PROTECTION OF THE LUNG. It is to render the inspired air acceptable to the lungs for the consummation of the proper gas exchange that the nose assumes its next important role. The alveoli require relatively constant conditions for effective respiration. The tissues are delicate and must be protected from extremes of temperature, insufficient humidity and foreign matter.

While the air passages of the lung have their own facilities for the removal of foreign matter, the functions of heating and moistening the air fall entirely to the nose, there being no structures below the glottis devoted to these purposes.

SELF CLEANSING AND PROTECTION. While discharging these duties the nose has the additional burden of keeping itself in order, and ridding itself of dust and other foreign matter which it filters from the air. Nothing could be more effective for this purpose than the ciliary epithelium and its

2. Moncrieff, A.: Nasal Obstruction in the New-Born. B. M. J. 1:1295 (June 27), 1936.

3. VanGilse, P. H. G.: Vorführung eines Kinofilms, die Atmung bei einem Neonatus mit doppelseitiger Choanalatresie. Acta Oto-Laryng., 24:205, 1936.

blanket of mucus which constitute a veritable belt conveyor and which will be considered in detail farther on. Vital to this mechanism is a sufficiency of moisture which while not great, must be constantly maintained. Restriction or absence of moisture for even the shortest periods—a matter of minutes—may destroy the cilia which then need to be regenerated. As infection may more easily occur while this is taking place, it is of prime importance that humidification be continuous.

MOISTENING. The wiping action of the palate,[4] which completes the cleansing process at the pharyngeal end, likewise depends upon the proper moisture of the apposing surfaces of velum and pharyngeal wall.

Not only does the patient who suffers from a pharyngitis sicca have some difficulty in swallowing, but he has a constant desire to do so. This is the effect partly of simple irritation and partly of the accumulation of dried mucus just beyond reach of the swallowing mechanism.

Farther down, the larynx improperly moistened is first burdened with inspissated secretions, and later undergoes what is called a "piling up" of the mucosa, a symmetrical hyperplasia involving chiefly the posterior commissure. This causes persistent clearing of the throat and a chronic hoarseness which are not only exceedingly difficult to treat but may result in chorditis nodosa or pachydermia laryngis, or may conceivably promote malignancy.

Still lower in the respiratory tract the trachea, deprived of the proper moisture, is unable to cope with the dust-laden mucus which accumulates upon its surface. Strings of ropy

4. Sluder, Greenfield. Die Wechselbeziehungen zwischen Aktion des Pharynx und des weichen Gaumen, etc. Archiv. f. Laryng. und Rhin., 1915.

secretions adhere to its walls and are removed only through violent coughing, at first only on rising, but later at intervals through the day. These conditions are seen most frequently in older people, or in debilitated patients, and are relatively common at the end of winter after the mucosa has been subjected for months to soot and to furnace heat.

HEATING. Tantamount in importance to humidification of air is heating. As has been suggested, the tissues which come in contact with inspired air during its short stay in the respiratory tract are delicate by the very nature of their functional requirements, and behave badly at low temperatures. This is true not only of the pulmonary alveoli the walls of which are but a single cell in thickness, but also of the cilia, which move slowly when chilled. Although sustaining no permanent damage their efficiency is temporarily reduced.

The turbinated bodies are well suited to their function as radiators of heat. The arrangement of blood vessels in these structures is at once an indication of the volume of blood which they can accommodate and the rapidity with which it may circulate and radiate heat.

FILTRATION. Filtration takes place in two ways: The vibrissae about the anterior nares filter out only the very coarsest bodies; insects, leaves and such. Smoke, powders, pollens and dusts pass through much finer filters than this, and must be removed by impingement. Air currents passing over the moist mucosa in curved pathways and being projected against the mucous blanket deposit their dusts, which are caught by it and retained to be conveyed to the pharynx and swallowed.

Undoubtedly this process is rendered much more effective through the adsorption of particulate matter by the nasal walls

because of a surface charge which exists upon them. The extent of this charge is somewhat dependent upon conditions surrounding the individual. It may be very small, but is often large enough to attract finely divided matter from a distance of two or three centimeters.

FUNCTIONS OF THE SINUSES. Apart from the nose proper the sinuses have since time immemorial been recognized as having functions of their own. They have on the whole aroused more speculation than investigation and many of the functions attributed to them are fantastic.

Under "theories which have been advanced from time to time and have the most semblance of probability" Skillern[5] in 1923 listed six. His introduction indicates the skepticism with which he himself regarded them all.

The list itself is a commentary upon the readiness with which unproven hypotheses find their way into print, on the principle no doubt that any explanation however incredible is better than none at all.

Without going too deeply into the subject it is of interest that such ideas as the following were advanced by the leading savants of their times: that the sphenoid serves to hold the air before it enters the brain; that the sinuses form the humour with which the eyes are moistened and lubricated; that children's noses are always running because the sinuses are not sufficiently developed to serve as reservoirs for the nasal mucus; that sinuses suck the impurities out of the blood and hold them.

5. Skillern, R. H.: The Accessory Sinuses of the Nose. J. P. Lippincott Co., Phila., Fourth Edition, 1923, p. 25.

In medicine, when we know the answer the conjectures of our forebears seem a trifle quaint. Regrettably in this case even we do not know the answer.

Skillern's list:

1. They are remains of rudimentary structures which in lower animals serve as adjuncts to olfactory structures.[6]

2. They assist in the olfactory function by evenly distributing the inspired air in the olfactory region.[7]

3. They lighten the bones of the skull for better balance.[8]

4. They add to the resonance of the voice.

5. They secrete mucus for the purpose of keeping the nasal chambers moist.[9]

6. They assist in moistening the inspired air.

The early literature teems with the writings of those who having pointed out the vagarious theories of their predecessors replace them with others of their own, equally vagarious, and equally lacking in fact.

These troublesome structures are still being evaluated in the light of an insufficient knowledge. Even so accurate an observer as Luschka reasons that the sinuses "cannot possibly be of assistance in supplying mucus to the nose because the unfavorable situations of the ostia (except the frontal) preclude

6. Ingersoll, J. M.: The Function of the Accessory Cavities of the Nose Ann. of Otol., Rhin. and Laryng., 15:757, 1906.

7. Braune and Clasen. Die Nebenhöhlen der menschliche Nase in ihre Bedeutung für den Mechanismus des Riechens. Zeit. für Anat. Bd 2, 1877.

8. Vesalius (1542) and many others, cf. Wright, Jonathan: History of Laryngology and Rhinology, Second Edition, Lea & Febiger, Phila., 1914, p. 168.

9. Placentinus, cf. Veslingius: Syntagma Anatomicum Appendix pars XIX, 1637—and many others.

the possibility of their having this function." Although the observation was made some thirty years after the characteristics of ciliary action became known, this author and his contemporaries reckoned without them, and so it was to continue for still thirty years more.

One accepts with chagrin the conclusion that our own failure to attribute a demonstrable function to the sinuses at this writing still rests upon our ignorance of some probably simple phenomenon which thus far has escaped our notice.

VESTIGEAL OLFACTORY ORGANS. There is at least nothing to controvert the belief that the sinuses were once involved in olfaction and certain things give it weight. To begin with, comparative anatomists find evidence of such relationship. The conformation of the accessory sinuses in the macrosmatic animals adds considerably to the actual surface exposed to particles of odorous substances or "odorivectors" in respiration.

It is not unlikely also that slow exchange of air about the ostia of the accessory cavities as compared to that in the respiratory tract may serve to cause odor laden air to pause in the nose long enough to be detected or appreciated, or analyzed by the animal. A fleeting scent may thus be caught and held for identification. One does not need to be a gourmand to appreciate that time is required and a lingering of the *aromatic impression, for a nice discrimination of the "gustatory"* odors.

That the sinuses are an adjunct to olfactory function, "evenly distributing the inspired air in the olfactory region"[10]

10. Braune and Clasen: *loc. cit.*

will be difficult to accept until some more convincing evidence can be brought to bear than has been thus far advanced.

Ingersoll[11] has carefully worked out the anatomy of the olfactory organs of many of the lower animals. His demonstration of the fact that the sinuses or their prototypes in lower animals house certain elaborate organs of smell, does not necessarily prove that the sinuses as found in man are merely vestiges of these prototypes, nor does it explain why the sinuses persist to an elaborate degree in man, where no vestiges of these special sense organs themselves are found.

Further Paulson and Hartz[12] find that anosmic animals are often equipped with large sinuses, and Arthur Preyer[13] points out that young children and the lower apes have a very keen sense of smell and no sinuses at all or very small ones.

The presence of olfactory nerves or vestiges of olfactory organs has never been satisfactorily demonstrated in the sinuses of man. Jacobson's organ presents such a vestige on the septum, and were the sinuses rudimentary or vestigeal olfactory organs one might expect to discover some similar trace there.

Vocal Resonators. That they may have some effect upon the timbre of the voice[14] is also true, but the positions of the sinuses and their ostia are not such as to make them efficient as resonators. Furthermore, large sinuses are by no

11. Ingersoll, J. M.: Some Points in the Comparative Anatomy of the Nose and Accessory Sinuses which Account for the Variations in these Structures in Man. Trans. of the Laryng., Rhinol. and Otol. Soc., 1922.
12. Hartz, H. J.: Physiology of Nose and Sinuses. Laryngoscope, 1909, p. 958.
13. Preyer, A. (1884): Coffin: Development of Acc. Sin. of Nose. Am. Jr. of Med. Sciences, Feb., 1905. Frers: Studien über die postembryonale Entwickelung der Nebenhöhlen der Nase. Vehr. d. Vereins deutscher Laryng., 1909, p. 191.
14. Spiegel, 1645; Voltini, 1888.

means invariably accompanied by resonant voices. Guinea pigs and rabbits, for instance, have relatively large sinuses and shrill, irresonant voices. Giraffes have tremendous sinuses and no voice at all.

Whether or not they actually do add resonance to the voice is difficult of proof, as obstruction of the ostia is usually accompanied by other changes in the vocal organ as well; and if they do, it still does not follow that this is their essential purpose. In order to make such a contention really convincing it would be necessary to record the voice of a singer and then repeat the experiment after filling or otherwise rendering the sinuses nonresonant; but this would have to be done without interfering with the patency and continuity of the nasal passages, the freedom of which is essential to voice production. Singers are seldom anatomists and the distinction between nasal passages and sinuses is difficult to them.

Nor does comparative anatomy clarify the situation. The tremendous frontal sinuses of the elephant (which reach from his brow to the foramen occipitale magnum) might conceivably add to the timbre of an occasional trumpeting, but how account for the veritable bony balloon surrounding the tiny brain of the silent giraffe?

Many fine distinctions have been made regarding the conditions of the nose responsible for the production of the so-called nasal tones. Naturally the acoustics of the nasal chamber undergo minor changes with every variation of nasal patency, palatal tension and oral opening.

Certain tones are produced in singing upon which the opening or closing of the nostrils has no effect. These are largely tones produced with a wide-open mouth. In this situation the

tensing of the palate and hence the opening or closing of the nasopharynx is a small matter. With the oral opening somewhat reduced by partly closing the mouth, by elevating the tongue or by dropping the soft palate, the nasal element becomes much more pronounced. Production of sound under these conditions is known as "rhinolalia operta." The opposite condition, that produced for instance by the swelling of the membrane or a cold in the head, is called "rhinolalia clausa."[15]

Rhinolalia operta is the condition found in paralysis of the soft palate, in cleft palate or any other situation which prevents the closing of the pharynx, although the nasal airway is clear.

Animals having no sinuses include amphibians, monotremes, seals, walruses and sea-lions.

Animals having relatively small sinuses are the reptiles of the higher orders, that is, including and above crocodilians, carnivora, and rodents, insectivora, bats, sheep, goats, cats and monkeys.

Ruminants have large frontal sinuses, as do elephants, birds and giraffes.

Schaeffer[16] cites the description by Moodie[17] of the casts of the paranasal sinuses of two early tertiary mammals, oreodont (described by Leidy as ruminating hogs) and an early bear-dog (Daphaenus). These natural casts indicate an extensive development of the frontal and maxillary sinuses in the two species.

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15. Negus, V E.: The Mechanism of the Larynx. C. V. Mosby Co., St. Louis, 1930, p. 414

16. Schaeffer, J. P.: Nose and Accessory Sinuses, p. 350.

17. Moodie On the Sinuses Paranasales of Two Early Tertiary Mammals. Jour. Morph. Vol. 28, 1916.

STRUCTURAL LIGHTNESS. The belief that the purpose of the sinuses at least in part is to lighten the bones of the skull in order that proper balance may be obtained has been supported by many investigators since Vesalino in 1542 and Highmore in 1681. "Nam natura, cum vult extendere, et non addere materiam, inflat et faciat ut illae partes sint leviores" (Fallopius).

That they do actually lighten the skull is indisputable, but Braune and Clasen[18] find that, were the sinuses replaced with solid bone, the weight of the human head would be increased but 1 per cent. As for balance, our heads are not perfectly balanced, nor do individuals who lack a sinus or two go about with their heads hanging or hold them erect with effort. Furthermore, many quadrupeds whose heads are not even approximately balanced have large sinuses.

MOISTENING AND HEATING. The theory that these cavities are in some way an adjunct to the nose in warming and moistening inspired air is based upon a misconception of nasal air currents and is quite untenable. Even when the ostia are large and unobstructed, there is no air circulation whatever in the sinus and almost *no air* exchange. Furthermore, the sinus mucous membrane is practically devoid of glandular tissue and is inefficient in furnishing moisture beyond the very small quantity required by the sinus epithelium itself.

INSULATION. There is much food for thought in the suggestion that the sinuses behave as insulators, protecting some very sensitive structures from thermal variations set up in the nasal passages, whose mean temperature, even under average conditions, is known to be less than that required for the best

18. Braune and Clasen: loc. cit.

functioning of the eyes, the pituitary, the brain and the medulla.

These cavities constitute an air jacket about the nasal fossae closely resembling the water jacket of a combustion engine.

It cannot be gainsaid that these chambers, containing air free from circulation, are effective insulators. It is also noteworthy that in animals without sinuses as, for example, the seal the nasal passage is nowhere in relationship to the eye or the brain, approaching the former in only a very restricted area and being entirely separated from the latter.

It might be objected that many tropical animals have large sinuses but it should be borne in mind that even here the nasal mucosa is normally below the general body temperature, owing to evaporation, and the sun beats down upon the skull.

There may, of course, be a grain of truth in most of these theories, and the various effects are produced, in a measure, but none of them is in itself sufficient to explain the presence of the rather complicated arrangement and the irregularities in shape, size and development of the sinuses.

To the theories already discussed the author has added two of his own, which are propounded in detail in Chapter IV.

There are many seemingly simple things about the nose which still keep us guessing:

It is fairly obvious that the swelling or the collapse of the nasal tissues is a function of the autonomic nervous system but one cannot help wondering just what, in a healthy and ostensibly undisturbed nose, motivates the sudden and almost imperceptible swelling of one turbinate to close one side. Why

that side? And why out of a clear sky *without so much as its* owner's moving a muscle or even vaulting a mental hurdle, does it presently open up again?

If this valve action is purposeful then what is its purpose? Answers spring to mind, but they are at present only scientific guesses.

Fig 2 Photograph, Sagittal Section of the Seal's Skull.

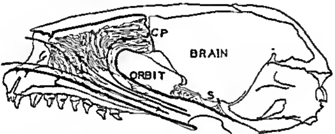


Fig. 3 Diagram, Sagittal Section of the Skull of the Alaskan Seal, which has no accessory nasal air cavities, indicating the pathways of inspired and expired air. The turbinated bodies are so ridged as to prevent the direct impact of inspired air against the cribriform plate. The orbits are separated by nothing more than a thin plate of bone, and lie between the air passages and the brain.

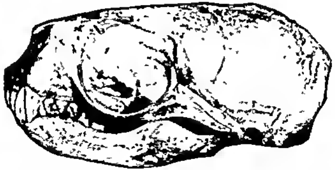


Fig 4. Skull of the Alaskan Seal, intact. Note the size of the orbit which is in juxtaposition to its fellow on the opposite side.

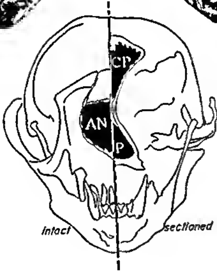


Fig 5. Skull of the Alaskan Seal, showing the turbinated bodies in the nasal fossae.

Fig. 6. The same skull, from which the left anterior half of the nasal bones and the other nasal structures has been removed. On the right above, the cribriform plate, below, the passage to the pharynx.

Fig. 7. Diagram of the preceding. AN—Anterior Naris, CP—Cribriform plate, P—Pharynx.

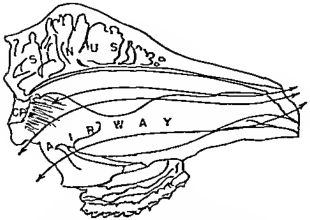


Fig. 8. Diagram, sagittal section of the skull of the Giraffe from the cribriform plate forward.

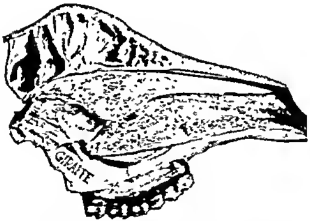


Fig. 9. Photograph, sagittal section of the skull of the Giraffe from the cribriform plate forward. Note the direct airway to the cribriform plate and its relation to the eye and brain in contrast to that of the seal. A large sinus above. (From the collection of Dr. P. F. Swindle Reproduced by his kind permission.)

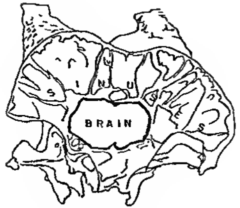


Fig. 10. Diagram, frontal section of the skull of the Giraffe.

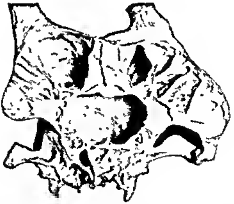


Fig 11. Photograph, frontal section of the skull of the Giraffe. Note the tremendous pneumatization, and the relation of the sinuses to the brain and the horns. (From the collection of Dr. P. F. Swindle, reproduced with his kind permission.)

CHAPTER II

HISTORICAL NOTES

LAPSE OF INTEREST 1890—GALEN—XVI CENTURY—THE BIRTH OF PHYSIOLOGY—SCHNEIDER—WILLIS—STENO — CASSERIUS — VESLINGIUS — THE MODERNS—MIRRORS—EARLY DAYS.

LAPSE OF INTEREST, 1890. There are several features in the development of nasal physiology which arouse one's curiosity, but there is one above all others requiring explanation, namely a hiatus, a lapse of interest in the subject which seems to have occurred between the late '90s and the very recent past. Whether this was because or in spite of the excessive activity which manifested itself in the preceding fifty years is not clear. The Transactions of the American Laryngological Association, for example, in the decade ending in 1939 reveal in a total of 195 presentations only six communications on subjects bearing even slightly upon the physiology of the nose. During the same period the Proceedings of the American Laryngological, Rhinological and Otological Society contain only seven in a total of almost 600!

The discoveries of the previous generation were by no means so conclusive as to warrant their unquestioned acceptance and yet textbooks continued to quote theories based upon them, which even in the quoting were recognized to be fallacious. In the matter of sinus function, for instance, writers persistently reverted to the conjectures of the ancients and were content to admit in passing that their ideas were probably without foundation, the while overlooking a wealth of appar-

ently accurate experimentation recorded in the middle of the last century. Authors in those intervening years, those dark ages almost without benefit of laboratory, display a disregard for physiology which might have been contempt but was, to do them justice, only complete innocence.

For one accustomed to peruse the sketchy accounts of nasal physiology in most textbooks, often confined to a paragraph or two sandwiched between a description of office equipment and the blood supply of the nasal septum, there waits an agreeable surprise if he is willing to make the effort to plunder his library stacks.

This he must do with discrimination, for his material will come from all manner of sources. Most of what he will read about nasal physiology has been discovered by someone not vitally interested in the nose. It is often a by-product far removed from the problems of rhinology. Some of it comes from zoologists working with tissues not human, but from animals whose habitats, environments and genealogies differ from our own.

GALEN. But to begin at the beginning, which is to say with Galen, his first important utterance with regard to the nose seems to be in criticism of something written by Plutarch 100 years earlier about a conception of Plato. To this Galen says "if Plato supposed that we take all of our drink into our lungs it is proper to remark that he was ignorant of a very evident matter. If he supposed, however, some part of the drink passing through the trachea is carried to the lungs, he announces a thing possible and like other matters concerning which physicians and philosophers may disagree among themselves."[1]

1. Wright, Jonathan: *A History of Laryngology and Rhinology*, Lea and Febiger, 1914, p 48.

Thus at least we have a precedent for the uncertainty which exists today concerning kindred matters. To Jonathan Wright, upon whose personal researches we depend for much that is known of the history of our specialty, we are indebted for the following characteristically pungent observation: "Some of the passages in the writings of the Aesclepiadae seem ridiculous to us, but we should keep constantly in mind the charity which our successors in their histories will have to extend to the productions of our own times. Indeed, in looking over the various commentaries on Hippocrates from Galen's time to our own, it is curious and not a little amusing to observe how careful each critic is to point out the errors Hippocrates committed in not being in accord with the doctrines of the critic's own time, which are now as obsolete as those of Hippocrates."[2]

While some of Galen's ideas may have been a bit fanciful, such as that the uvula contributed to the strength and beauty of the voice and that its amputation not only ruined the voice but killed the patient from cold in the lungs, nevertheless he observed accurately that inspiration did not take place directly into the trachea but was deflected in a curve before arriving there. The advantage of this he expressed as being two-fold: first, "because the air surrounding us is at times quite cold and the lungs then would be chilled" and second that in curving through the nose small particles of dust or ashes would fall upon soft and wet surfaces which are somewhat mucilaginous and which would retain them until blown or spit out.[3]

Galen recognized also that the nose was essentially a respiratory organ and that the mouth was in no way adapted to that purpose except as an accessory opening in case of nasal obstruction.

2. Ibid Page 46.
3. Ibid. Page 80.

XVI CENTURY. It is scarcely the province of this book to dwell upon the conceptions of the ancients, for a detailed account of which the reader is referred to Wright's classical work.

The beginnings of modern investigations into the physiological processes may be detected in the 16th century with Servetus, Brasavola, Willis and Vesalius but they developed momentum a century later with Leeuwenhoek, Schneider, Steno, Fallopius and Veslingius.

The latter expresses the divergent contemporary views of the sinuses; "each one forms his own conjectures" he says, "some as Placentinus, claim they contain mucous humor, others that they serve to make the voice more resonant because in those who speak badly they are not found. Some think the air is elaborated in them for the generation of the animal spirits. Spigelius thinks they are for drawing in the odor." He himself was of Galen's opinion, namely, that nature, wishing to extend structures without adding material simply inflated the parts thus making them lighter.

Schneider's opinion that the sinuses were empty under normal conditions and not filled with "animal spirit" was not generally accepted by his contemporaries, in fact, a century later Boerhaave pointed out that the reason why children's noses are always running is that the accessory sinuses are not sufficiently developed to contain the mucus.

Scientific nasal physiology, the basis of present-day conceptions, actually took form about 1850. At this time some ideas were beginning to crystallize regarding vasomotor reactions consequent upon the irritation of the mucosa.

THE BIRTH OF PHYSIOLOGY. Wright puts the birth of general physiology in the early part of the 16th century at

which time there developed an interest in the circulatory system, the differentiation of veins, the discovery of valves, the existence of the pulmonary circulation.

Willis, a contemporary of Schneider, who believed in the existence of a nervous fluid, conceived the nasal fluids as the drip from the cerebral fluids into the nose via the olfactory nerves. "Within the cavity of the nose", he writes, "there are tubular membranes which contain thickly woven sensile fibers. In these membranes there are a number of slender nerves given off from the mammillary processes through the cribriform plate."[4]

This conception persisted in many quarters for a long time, and vestiges of the idea still linger in the French term for a cold, "rhume cérébral."

Van Ruysch, who regarded the nasal glands as a source of the secretions, conceived of these as being simply tiny openings from the blood vessels through which serum was allowed to seep.

The true nature of mucous glands was probably first appreciated by Steno[5] (1662).

The turbinated bones appear to have been first described in any detail by Casserius in 1610, although previous mention had been made of them. Casserius characterized them as "oblong little bones which may be called spongy, and seem like the steps of a ladder because one is placed above the other. . . . They are bones not cartilages; 'turbinata ossa' they are rightly called. They are usually three in number,

4. Willis: De Anima Brutorum. De Senus Olfactus, Cap. 13 (Opera Omnia., Amst., 1682, p. 64). Wright's translation.
5. Steno, N.: Observationes Anatomicae, Quibus varia Oris Oculorum et Narium Vasa describuntur, 1662.

indeed this many at least always." As to their function he contributed no new ideas beyond Galen's generalization that the structures of the nose break the force of the air, and cleanse and warm it.

Veslingius in 1637 is recorded to have observed regarding the sinuses that "there is much doubt as to their use", which doubt as we have noted has not been dispelled at the present writing. The quotation is from a paper by Ross Hall Skillern[6] entitled, "History of the Sinuses", read in 1924 before the American Laryngological, Rhinological and Otological Society, and it is typical of the thought of the period that among the 44 references in the paper these eight words of Veslingius constitute the only mention of physiology.

THE MODERNS. The remote origins of our more specialized knowledge present a fascinating field for study, but beside this they are a constant reminder of man's peculiar obtuseness in failing to recognize what is before him.

It would seem that, owing to the very volume of research emanating from the 19th century, little about the nose could have remained unknown or at least uninvestigated. Indeed, much which closely concerns us and should early have become part of our routine teaching, was actually recorded, yet went unnoticed through the years. This is partly because rhinology did not exist in the days when these discoveries were made. They were vital to nobody, and often of purely academic interest even to their discoverers.

The middle and later decades of the 19th century fairly bristle with articles about physiological matters important to rhinologists. They were incidental, however, to some problem

6. Skillern, Ross Hall: History of the Sinuses. Ann. of Otol., Rhinol. and Laryngol., 34:286 (Mar.), 1925.

in the broader subjects of respiration, circulation or anatomy on the one hand, or pure biology on the other, without any immediate clinical connotations.

MIRRORS. The origin of the twin specialties of rhinology and laryngology is definitely dated. In 1855 the singing teacher Manuel Garcia described his laryngeal mirror. In 1857 Ludwig Türck applied it diagnostically. In 1858 Johann Czermak added the concave, perforated head mirror without which, as he himself pointedly puts it "laryngoscopy would have been a still-born child." At that, it spent a sickly adolescence.

The fifteen years following the introduction of these mirrors were devoted to the development of laryngology alone before it seems to have occurred to anyone to apply these new instruments to the nose. Wright points out that in the first edition of Solis Cohen's book on Diseases of the Throat, published in 1872, and containing more than 200 pages, 90 are devoted to the nose. In the following thirty years the proportions were reversed. These early texts made no more mention of nasal physiology than do those of the present day.

EARLY DAYS. To what is one to attribute this singular indifference to physiology in our specialty? Probably more than anything else to the fact that modern rhinology and modern surgery were born together. The rise of the Listerian antisepsis and the tremendous surgical advances which were made possible by it seized the imagination of the pioneers in rhinology. Medical thought advanced in terms of surgery. The nose was accessible and the nasal blockades attendant upon so many pathological conditions yielded promptly and miraculously to surgical measures. The recently discovered bacteria could be liberated at will from the infected cavities

and the major laryngological problems seemed to be largely where to cut, and how promptly.

Under other circumstances a healthy curiosity might presently have arisen regarding the physiological processes of the nose, but there was no time. The age of specialism was at hand. It became fashionable to consult specialists, and specialists were in demand.

Young medical men with sufficient means and interest to devote the necessary years to graduate study were few. These developed large practices, became prosperous and inordinately busy—circumstances not conducive to progress in basic science.

After some twenty years had elapsed and more clinics and clinical courses had become available, the ranks of specialists filled to overflowing. Under the stimulus of a little leisure and the pressure of competition (and fostered, no doubt, by the growing conviction of the laity that even modern rhinology was no better that it should be) interest in the basic sciences was reborn.

It began in the field of pathology, attributable in a large measure to the emphasis given to that subject by the American Board of Otolaryngology inaugurated in 1925. It was evidenced in the demand for better training in this country, coupled with the deterioration of the continental clinics as a result of the European wars, and has ultimately led to the establishment of numerous graduate courses in medical centers with faculties adequate to the requirements.

Physiology has been the last of the basic subjects to appear in most of the curricula. This is clearly due to the difficulty of correlating the material for teaching. Unfortunately, except for a few outstanding sources, the work is scattered

through the literature of half a dozen decades and a dozen countries.

As might naturally be expected, some of the numerous experiments and observations reported during the middle and latter eighteen hundreds were inaccurate, incomplete or fanciful.

In some instances careful observations led to interpretations which they did not justify; in others deductions were made from the behavior of models and apparatus which did not reproduce or parallel natural conditions; in still others unsupportable statements found credence simply because they issued from high places emphatically.

Still there arose above all this welter a *few* towering figures, scientists whose work though oft repeated has never been shaken.

Braune and Clasen in 1876 set down the air-pressures developed in the nose under various conditions. (Fifty others have repeated their experiments and have arrived at the same results.) The rest of the work of these authors, as will be noted, receives the same confirmation.

Similarly the name of Zwaardemaker is inseparably identified with olfaction, a remarkable feat in the face of the nine hundred articles dealing with the sense of smell published by others in the half-century in which he wrote. In the same field appear prominently such names as Aronsohn, Cloquet, Fischer, Benzoldt, Henry, Passy and Heyninx. Zwaardemaker's preeminence rests largely upon his classical monograph, "Die Physiologie des Geruchs" published in 1895.

With Aschenbrandt, Kayser and MacDonald, all writing in the 'eighties, originated many of the views now held in regard to the nasal passages as avenues of respiration.

While the morphology of the cilia received wide attention about the same time, most of our pertinent knowledge regarding these structures dates back not more than three decades. The present-day interest in the human respiratory ciliated epithelium seems to have been kindled by the appearance of a small volume, "Ciliary Movement" by J. Gray in 1928, and an article by Lowndes Yates describing the ciliary pathways in the nose and the sinuses published some four years earlier.

Jonathan Wright in his later years was much occupied with the manifestations of what he termed the "primordial forces" at work in local resistance to infection, and other phenomena of the cell walls, surface charges and the penetrability of membranes.

Surprisingly few of the prominent names in rhinology can be included in this list. The great majority of these men wrote on clinical subjects alone, and such as devoted themselves to the basic sciences confined their attention solely to anatomy and histology and to the principles of surgery.

The references in the present volume constitute a comprehensive list of contemporary and recent contributors to nasal physiology, and therefore require no further mention here.

Many of these investigators are still at work and are showing an ever-increasing interest in physiology. If much of their effort finds its prototype in the laboratories of fifty years ago it is none the less important, for two reasons: first because of inaccuracies to be found in the earlier publications which still require correction, and second because the modern worker has a great advantage over his predecessor in point of equipment and the collateral knowledge which he can bring to his problem.

non-breakability this is highly efficient. From the standpoint of natural selection the arrangement is sometimes advantageous, at others disastrous, as the plastic surgeons well know.

Four causes of nasal vestibular obstruction are mentioned by Kyle: (1) faulty formation of the lateral cartilages; (2) lack of development caused by early nasal obstruction; (3) atrophy through disuse of the dilator muscles; and (4) the congenital slitlike orifice found in long, pointed noses.

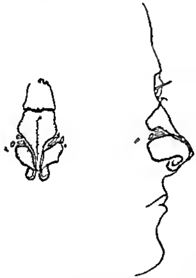


Fig. 12. Cartilages of the external nose

Through an overactivity of the dilator muscles at their insertion into the inferior border of the greater alar cartilage this cartilage may be rotated so that its upper margin is turned medially and encroaches upon the airway.

In the case of insufficient cartilaginous support the alae collapse under the negative pressure of inspiration. Educational methods are usually sufficient to overcome this condition, unless an actual muscular incapacity exists, in which case surgical intervention is required.[1]

VIBRISSAE. The vibrissae, the stiff hairs which project into the anterior nares, are obviously a protection against the coarser foreign bodies alone: leaves and insects. The downward

1. Lillie, H. I. and Simonton, K. M.: Nasal Obstruction Caused by Collapse of the Nasal Alae. Ann. Otol., Rhin. and Laryng., 48.60 (Sept.). 1939.

direction of the nostrils themselves is a protection against the entrance of dust, rain and other gravity propelled matter.

Any finer-meshed screen at this point would interfere with free breathing and the sense of smell.

Bones. The bones of the face, unlike those elsewhere in the body, are not developed from cartilage but are produced within sheets of connective tissue and arise by intramembranous development.

Standing practically alone in its decade is a short dissertation by Henry J. Hartz on the physiology and development of the nose.[2] This author points out that there are two major periods of facial growth, the first from birth to the eighth year, the second from puberty to maturity. During the first year the development of the head and face is general, but after that the face begins to grow disproportionately to the growth of the cranium, activity beginning about the lower structures of the nasal cavity.

From the second to the fifth year, growth is chiefly in breadth, but from the fifth to the seventh year the gain in length is more pronounced. At birth, a line prolonged back from the hard palate would intersect the junction of the basilar process and the sphenoid. At the age of three it intersects the middle of the basilar process, and at six the edge of the foramen magnum, which is approximately the adult position.

The dimensions of the choanae also point to this progression. At birth their vertical diameter is about 6 mm., at the first

2. Hartz, H. J.: Remarks on the Physiology and Development of the Nose and Accessory Sinuses and Nasal Reflexes with Special Reference to the Function and Importance of the Turbinated Bodies. Ann. Otol., Rhin. and Laryng., 18:709 (Dec.), 1909.

year about 12 mm. and by the seventh they have reached approximately adult size.

The development of the nasal space in the antero-posterior direction through the growth of the maxilla gradually changes the orthognathous face of the child to the prognathous adult form. Concurrently with the eruption of the deciduous teeth *there is a rapid development of the* anterior nares.

Individual variation in the form of the nose is greater than that found in the cranium, and much greater than bodily variation as a whole.

If it is true that mutual compensations in form occur between contiguous parts then these nasal variations must be the result of adjustment to the adjoining bones of the skull, although it is conceivable that disproportion among the constituent structures of the nose itself may have some part in the variation.

It may be said that the human nose in general lying more under the cranium than in front of it shows a greater tendency to depart from the norm. This tendency often exhibits itself in the form of a deflected septum.[3]

Pitkin makes the plausible observation that an internal nasal compensation seems to exist for the varied relationships of the nasal floor to the nasal roof. He finds this compensation somewhat exaggerated in the presence of septal deflection, but is unable to say whether it is the cause or the effect of the deflection.

External compensation seems to be found in the relationships between nasal and posterior cranial variations.

3. Pitkin, Carlos E.: An Analytic Study of Nasal Form. Ann. Otol, Rhin. and Laryng., 33:800 (Sept.). 1924.

He suggests that the failure of nasal response to such a variation may tend to restrict the size of the nasopharynx. In cases in which an unnatural cramping of the septum occurs the center of distortion is to be found in the area near the incisive foramen.

Nasal Walls. The contours of the walls of the nasal fossae and the septum are all-important. It is necessary to nasal health not only that all portions of the nasal fossa be accessible to air currents but that they shall be accessible only in the proper proportions, and that the streams of air shall proceed without too much eddying. If the middle and superior meatuses are disproportionately patent, abnormal drying takes place, and in its train appears a chain of symptoms: anosmia, headache, metaplasia, infection.

The stream of air shaped and directed by the constriction at the nostril, passes median to the anterior tip of the middle turbinate. The middle meatus is recessed to such an extent that the middle turbinated bone lies well lateral to the main air stream. This serves both to keep the dry, cold and contaminated air out of the meatus and to divert a proper proportion of the inspiratory stream to the olfactory area. Too little air in this region fails to make an olfactory impression; too much has the same effect, first because of the rapidity of the stream, second because of its obtunding influence, through drying and irritation, on the olfactory perceptors.

All the nasal structures are, in a sense, streamlined. This will be discussed further in dealing with air currents, but it is important to observe that the currents are determined entirely by the shape of the anterior nares, and that they merely pass over the turbinal structures without being further directed by them.

The face of the sphenoid and the choanae are also in such relationship to the air stream as to permit it to proceed unchanged.

NARES AND CHOANAE. The vertical diameter of each choana according to Schaeffer[4] is from 24 to 33 mm., the transverse diameter at the floor from 12 to 17mm. and at the roof from 7 to 10 mm. Estimation of the nasal section at this point is usually made by what is known as the choanal index: $\frac{\text{(transverse diameter} \times 100)}{\text{vertical diameter}}$

This section is larger in the female than in the male, in the proportion of 64.5 to 61.

The orifices are so related to one another in size, shape, position and direction that the demands of nasal ventilation are properly met. Thus the anterior naris is not only directed upward but it is constricted and is invariably smaller in section than the choana. If this were not true, or if a pathological condition existed which rendered the choana actually smaller than the naris, then the directional effect of the latter would be lost, and the air currents redistributed.

Patients have been observed with unilateral congenital choanal atresias, and while the sinuses on the obstructed side may appear dense in the roentgenograms there is no lack of development as compared with the normal side.[5, 6]

It is generally agreed that stagnation of mucus in the closed side is apt to result ultimately in sinus disease.

4. Schaeffer, J. Parsons, in Jackson and Coates: The Nose, Throat and Ear. Saunders Co., 1929, p. 10
5. Grove, W. E.: Choanal Atresia and Sinus Infection. Arch Otolaryng., 6:237 (Sept.), 1927.
6. Stewart, J. P.: Congenital Atresias of the Posterior Nares. Arch. Otolaryng., 13:570 (Apr.), 1931.

Ordinarily a complete congenital occlusion is manifested in infancy, as it interferes vitally with the infant's breathing and nursing. When the occlusion is partial, no matter how extensive, it may not be recognized for some time and occasionally persons reach adult life before the condition is diagnosed.[7]

Three of Stewart's patients had undergone other nasal operations for obstruction before the atresia was finally detected.

A difference apparently exists between the behavior of a nasal mucosa deprived of air after breathing has been established, and one in which, through congenital posterior closure, no breathing has ever taken place. In the latter condition normal, healthy tissues are often found in the nasal fossae, and there is also an absence of the hyperplasias and similar reactions usually encountered about the orifices of the eustachian tubes in cases of acquired obstruction. Thomson[8] observes that if both sides are occluded the hearing may be interfered with, and he adds that though there may be an accompanying asymmetry of the face "there is not the marked atrophy and arching of the palate said to occur when one nostril is artificially occluded in young animals. It is noteworthy that this complete atresia of the nose, even with entire mouth-breathing, does not entail the chest deformity, narrow nostrils, alar collapse, deflection of the septum and changes in the ears which are frequently attributable to partial stenosis or to chronic nasal infection or to both."

7. Schaeffer, J. Parsons: Atresia of the Choanae: Its Incidence, Types and Cause. Arch. Otolaryng., 18:555 (Oct.), 1933.
8. Thomson, St. Clair: Diseases of the Nose and Throat. Fourth Edition. Appleton Century, London, 1937, p. 101.

PROTECTION OF THE OSTIA. The sinus ostia are protected from any inspiratory air currents, those of the anterior series opening high in the meatus, and the meatus itself being well out of line of the incoming air stream. Those of the posterior series are also out of contact with the air stream being high and laterally placed.

Air exchange through the ostia is sometimes attributed to the Bernoulli principle, upon which the atomizer and the Venturi valve are constructed, but this is a fallacious conception as the necessary constrictions do not normally exist in the nose in relationship to the sinus openings. The interchange of air must depend solely upon the pressure fluctuations set up by the thoracic excursions, in combination with the constriction at the naris.

That the ostia are always in a protected position adds weight to the belief that they are worth protecting, and that their function is impeded by direct blasts of dry, inspired air.

THE SEPTUM. The existence of a septum in the nose has speculative interest. It suggests that there is some advantage to a duplication of air tubes, and that two tubes of a given combined capacity are preferable to one of equal capacity. It may be, of course, that the now recessive Jacobsonian organ and other olfactory terminals once demanded the increased surface in this arrangement. It is scarcely likely that the septum adds any great mechanical strength to the nose and in some animals it undoubtedly does not; but it is true that the direction and distribution of air currents in the presence of a septum are very different than where no septum exists. Air streams from the two nares, unseparated by a septum, react upon one another to set up all sorts of eddies.

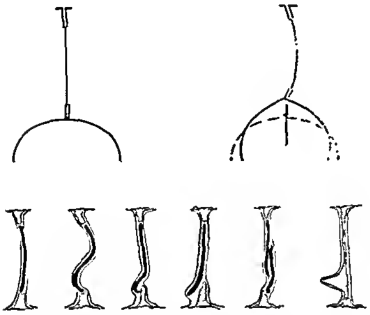


Fig. 13 Diagrams to show the effects of the elevation of the central portion of the dental arch upon the septum. Upper left, the normal relationships. Upper right, converging lateral pressures upon the bases of the arch force the center upward; the septum which rests upon it buckles. Below, various distortions of the septum caused by crowding from beneath.

Gill-breathing animals have their intakes far apart. In the course of a morphological change sufficiently radical to bring the nostrils together and to confine the air stream to a single trachea, the septum might very conceivably have been lost if it were not of some use.

The retention of two nares and two nasal fossae may have been to provide two intakes in case of the accidental obstruction of one.

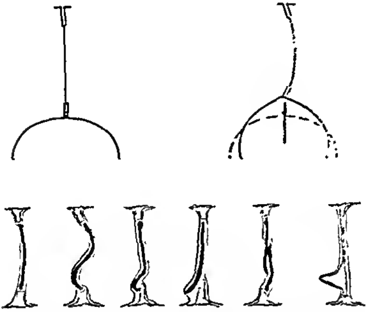
SEPTAL DEVIATIONS. Any mechanical factors which bring about bilateral pressure against the dental arch, among which mouth-breathing is prominent, tend during the developmental years to force it into a gothic arch. This so displaces the foundations of the septum that they buckle it or lose support of it altogether by allowing the cartilage to slip to one side.

Faulty bite may result in faulty development of the nasal structures. This is substantiated somewhat by the observation of Grahe[9] that the extraction of the molars of the lower jaw on one side may impair the development of the entire half of the skull, especially that of the maxillary sinus.

A structural peculiarity which appears to fly in the face of the functional demands and is the source of much trouble, is the disparate growth of the septum in relation to the surrounding bony framework of the nose, giving rise to all manner of bending and buckling, and upsetting the ventilation of the upper respiratory tract. Whether this is incidental to the readjustment of the human face in its metamorphosis from the type of the lower animals is problematical. Not only is it well known that this part of the face is in a state of flux, but also as just stated that a variable disparity exists between the rate and the extent of growth of the skull and the face.

Briggs observes that "there is a progressive tilting found of the prepituitary plane or the base of the frontal fossa of the skull from its upward and forward position in mammals, more forward in the simian, to the horizontal position in the highest type of man. This accompanies or is the result of the progressive forebrain pushing forward over the retrogressive nose and receding alveolar arches. In the meantime the parts

9. Grahe, K.: Trans. of the Collegium Oto-Rhino-Laryngologicum, Frankfort-on-Main (Sept.), 1930.



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Gill-breathing animals have their intakes far apart. In the course of a morphological change sufficiently radical to bring the nostrils together and to confine the air stream to a single trachea, the septum might very conceivably have been lost if it were not of some use.

The retention of two nares and two nasal fossae may have been to provide two intakes in case of the accidental obstruction of one.

Close observation of the inferior turbinate and its action in its various states of dilatation and contraction suggests that it may be acting as a valve to regulate not so much the direction of air as the actual capacity of the nasal fossa by increasing or decreasing its section. Thus under the influence of heat and cold, rest and activity, irritative fumes and so on, the expansion and contraction of the inferior turbinate can readily determine whether the main air stream shall be confined to the high parabolic curve through the olfactory fissure and the middle meatus, or whether the lower spaces of the fossae shall be called upon to take an added part in the ventilation.

The turbinal mucosa is well-adapted to function as a valve controlling the inlet of the respiratory system. From the deep arteries branches emerge to form a capillary network in the tunica just beneath the epithelium and about the glands. From this network the blood flows into two strata of venous plexuses, which constitute an erectile tissue. Circular and longitudinal bundles of unstriated muscle are distributed along the walls of the vascular channels and the surrounding connective tissue which, responding to certain reflex stimuli, allow the plexuses to become engorged or depleted. This, of course, produces a great change in the mass of the tissue, and hence an inverse alteration in the section of the nasal fossa.

One is struck by the differences between the anterior and the posterior tips of the turbinated bodies in respect to their effects upon the air currents which meet them during inspiration and expiration. The anterior margin of the middle turbinate, for example, while it is vertical and therefore at an angle to the stream of inspired air at this point, retires laterally into the deep recess offered by the anterior end of the middle meatus. Therefore it has little influence upon the inspiratory

current which passes medial to it. The posterior tip, however, stands fairly free in the stream of expired air passing through the wide choana, there being no deep recess at this point to accommodate it. The result is that only expired air, eddying in the nose, enters the middle meatus.

The anterior tip of the inferior turbinate is considerably behind the channel of inspired air and lateral to the minor currents which flow through the inferior meatus. The posterior tip, on the contrary is relatively prominent, and is also exposed to the air coming through the choana.

VASCULAR CHANNELS. Structure further adapts itself to function in the minute anatomy of the turbinates, in which the blood vessels are laid out side by side longitudinally in such a way as to permit the maximum radiation of heat from their surfaces and at the same time the dilatation of the structures of the entire turbinated body without disarranging them.

GLANDS. The relation of structure to function is to be seen again in the distribution of glands on the conchae, and especially in the sinuses. Here they are found in the lining mucosa in direct proportion to the rapidity of air circulation and hence to the demand for humidity. In the immediate vicinity of the ostia, where air exchange takes place and where through both diffusion and convection air is brought to the sinuses, the glands are plentiful. On the opposite walls, where evaporation is at a minimum, they are few and widely scattered.

Not only is humidification thus regulated, but the mucus blanket is deposited upon the surface as it is required. Aside from the small demand for mucus away from the ostium, an excessive amount appearing too early in the journey to the

ostium, would result in a premature accumulation and a piling-up with which the cilia could not cope. The dissimilarity between the mucosae just within and just without the sinus ostia is very striking. A sharp differentiation takes place at the very margin of the ostium, glands of the nasal mucosa being well adapted to accomodate the large and rapid air currents in the nose, those on the sinus side of the ostium being only just sufficient for the air currents there.

COMPARATIVE ANATOMY. The turbinated bones in man are comparatively rudimentary. They have reverted to the primitive types present in the lower vertebrates.[12] In the fish, for example, which uses its turbinal structures entirely for olfaction they are mere ridges covered by olfactory mucosa. In the reptilian, to whose nose the function of respiration has been added, both olfactory and respiratory mechanisms are found. More highly developed and differentiated are those of birds. In the macrosmatic animals the olfactory area is enormously increased through innumerable buds, branches and convolutions. In man and the apes these structures have once more reverted to much simpler types. Certain of them, the fourth and fifth ethmoidal turbinals, and the nasal turbinal, represented by the agger nasi, are merely rudiments.

AUTHOR'S THEORY OF THE FORMATION OF SINUSES. In the readaptation of the facial bones to the fixed bones of the cranium may be discerned readjustments which may serve to throw some light upon the formation and the purpose of the sinuses.[13]

12. Ingersoll, J. M.: The Morphology of the Turbinals. Ann. Otol, Rhin., Laryng., 17:901 (Dec.), 1908.
13. Proetz, A. W.: Observations Upon the Formation and Function of the Accessory Nasal Sinuses and the Mastoid Cells. Ann. Otol., Rhin. and Laryng., 31:1083, 1922.

If one observes their occurrence, the manner, time, position and extent of their incidence, and their growth in relation to the growth of the skull and of the individual, certain outstanding phenomena are encountered:

The first of these is that the cranium early attains its full, or nearly full, growth, while the face develops slowly and undergoes various changes in shape and in position relative to the cranium. Second, the jaw grows as the deciduous teeth are shed and the permanent teeth erupted. Third, as the growing individual develops the need of an increasing supply of air, the upper respiratory passages widen and expand. Fourth, the face plays an essential part in these changes.

Froriep[14 15] measured the cranial and facial portions of the skull and estimated the ratio as

8:1 at birth.
4:1 at five years.
2:1 in the adult.

The still greater disproportion of cranium to face in the fetus requires only to be mentioned.

The change from the baby face to the adult face consumes roughly twenty years, which coincidentally or not, is the age at which the last of the sinuses, the maxillary, attains its full size.

Two portions of a bony structure are growing, the one very slowly, the other quite rapidly. Mechanically one may be considered as standing still, the other growing away from it.

14. Froriep: Schaeffer, J. P.: The Nose, Paranasal Sinuses, Nasolachrymal Passageways and Olfactory Organ in Man. Phila., 1920, p 46
15. See also Hartz· Ref. 12, page 10.

Fig. 14 Drawing of a Sagittal Section of an Infant's Head, superimposed upon the outline of an adult head, to show the similarity of the crania, and the dissimilarity of the faces.

For facility in demonstrating this readjustment attention may be directed for the moment to the frontal bone.

The frontal bone conforming, dorsally, to the brain, which remains constant in size and position, finds its caudal and ventral portions suddenly called upon to conform also to the changing position of the nasal and maxillary bones now rapidly developing beneath them.

If the two opposite surfaces of a bone are required to separate, *one from the other, only two mechanical means of accomplishing* this are conceivable: **(1)** The space created by the separation may be filled in with newly formed bone, fat or other substance, rendering it solid; or **(2)** an air space may be created. This is the author's conception of what actually occurs.

It is not difficult to conceive of this new-formed air space as arising from the nearest existing air cavity, where the line of cleavage begins, and naturally being lined with similar epithelial covering. The small communication which persists between the cavities is left for the equalization of air pressure.

Fig. 15. Diagram showing the direction of the greatest growth of the sinuses.

Thus the formation of sinuses may be necessary simply for a readjustment of contiguous parts, and one is not called upon to attribute to them any further functions, even though these may incidentally exist. In other words, the sinus appears not to be pushed out, bent upon some mission as is an eye, an ear, or a kidney, but rather to be "sucked" in from the nearest air cavity by retreating structures, themselves shifting to subserve their own requirements.

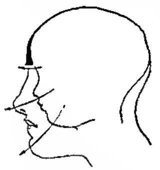

Fig. 16 Diagram indicating the development of the face and the conditions in the frontal region which may give rise to the frontal sinus

Both Coffin[16] and Frers[17] refer to the fact that the sinuses are poorly developed in children with adenoids; they consider this due to a lack of normal air pressure in the nose during expiration. The

16. Coffin: Development of Acc. Sin. of Nose. A. J. of Med. Sc., Feb., 1905.

17. Frers: Studien über die postembryonale Entwickelung der Nebenhöhlen der Nase. Vehr. d. Vereins deutsher Laryng., 1909, p. 191.

author considers it due rather to the underdevelopment of the face—the well recognized "adenoid facies."

In the frontal bone major ossific centers appear at the eighth week *in utero*. To quote from Schaeffer:[18] "The frontal sinus begins to develop during the fourth or fifth month of fetal life, but it is not topographically frontal until some time after birth. It develops slowly until the seventh or eighth year, then more rapidly up to the twentieth year, and increases somewhat in size up to old age." These *periods correspond precisely* with the growth of the face.

RELATED THEORIES. Van Gilse[19] describes the development of the sinuses from their original mucosal invaginations through what he calls the pneumatizing drive of the mucosa into the bone. He maintains that when this pneumatizing tendency is interfered with in one quarter, the surrounding bone may yield to the mucosa of a neighboring sinus. A similar competition may take place between the development of the cuspid tooth and that of the antrum. If the sinus develops into the bony area where normally the apex of the dental root should grow it will prevent the normal development of the tooth and prevent its *eruption*.

But one is forced to point out that it is within the bounds of possibility that here the advancing sinus occupied the area intended for the dental root as a *result* of the non-development of the latter, and not as its cause.

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18. Schaeffer, J. P.: The Nose, Paranasal Sinuses, Nasolachrymal Passageways and Olfactory Organ in Man. Blakiston, Phila., 1920, p. 45.

19. Van Gilse, P. H. G.: La lutte pour la place dans le développement des sinus nasaux. Acta oto-laryng., 22:468, 1935.

More attractive is the theory of Sitsen.[20] He finds no evidence that the mucosa has any ability to forge ahead on its own account and to pneumatize bone. He calls attention to the fact that even in very young individuals this tissue is confined to a double layer of ciliated epithelium which gives no indication of unusual activity, development or growth. No more aggressive is the basement membrane. Further, in cadavers at different ages the growth of the frontal sinuses is seen to be due to resorption of the spongiose bone. One cannot quite accept his deduction, however, that the driving force which brings about the penetration is the positive air pressure occurring during the respiratory air cycle. He is forced to explain the variations in the size of the frontal sinuses as due to varying air pressures, and hence to the degree of resorption. It is not shown for example why these variations in pressure should exist. If they are the result of obstructions anteriorly then there occurs an augmentation of negative as well as positive pressures which should neutralize them.

But if these sinuses are merely the result of the separation of the two tables of the skull then the disparity in their sizes may be readily accounted for by slight differences in the forces which act to separate them, or in slight variations of density in the bone where the separation takes place as stated above.

Again if air pressures alone were responsible for the pneumatization why should it ever cease since these pressures continue unabated throughout life?

Grahe[21] sought to prove or disprove the pressure theory by sewing up the external naris on one side of six rabbits under

20 Sitsen, A. E.: Bau und Entwickelung der Stirnhöhlen. Arch. f. Ohren-, Nasen-u. Kehlkopfh., 140:79, 1935.

21. Grahe, K.: Experimental Study of Development of the Nasal Sinuses. Acta Oto-Laryng., 15:141, 1931.

six weeks old. He found in the fact that no abnormality developed in three of these animals evidence to disprove it. Since, however, the anterior obstruction of nasal fossae does not mitigate air pressures in them, but on the contrary increases both the positive and negative pressures, his logic is not clear. Grahe also extracted the molar teeth of young rabbits at six weeks and succeeded in preventing the development of the antrum. The reason for this may be, as he asserts, the lack of growth of the alveolus induced by the absence of the pressure of mastication, or it may as well be the disturbance in the developmental processes of the maxillary bone brought about by the extraction of the teeth.

Schaeffer[22] "is strongly of the opinion that it is erroneous to think of the paranasal sinuses as forcing the face parts to develop or that the development of the sinuses is delayed until all other parts have grown sufficiently to permit of their expansion." He believes "that the developmental processes go hand in hand, and that when a certain time is reached a structure will normally have attained proportions for that period, regardless of related parts."

The author agrees with Schaeffer that it is difficult to suppose that the pneumatization of the sinuses should force the face parts to develop, but the reverse seems fairly plausible. The face parts develop because the individual has need of them: larger, stronger jaws, increased breathing space. The sinuses, which in such a rearrangement are nothing but unoccupied spaces, result incidentally.

This theory, so simply demonstrated in the frontal sinus is less obvious but still applicable to the case of the ethmoids and the sphenoids. Here too the development of the region, and

22. Schaeffer, J P.: loc. cit., p. 46.

even the direction of development, conform to the growth of the sinuses.

The initial ethmoid evaginations from the mucous membrane of the nasal cavity appear about the fourth month of fetal life. At term true ethmoidal cells exist, but pneumatization of the cells occurs with the growth of the face and the separation of the orbits. Measurements of these capsules from birth to the adult stage, show that their growth, unlike that of any of the other sinuses, is about equal in each of the three dimensions. The frontal sinus develops upward and outward and forward, along with the advancement of the face; the maxillary grows downward and laterally with the growth of the jaw; the sphenoid not ventrally, away from the nasal cavity, but laterally with the broadening of the adjacent parts.[23] The ethmoids, which lie centrally, follow the development of all these parts and increase in all directions. The question here presents itself: When the face grows away from the cranium and the spinal column, why does not the entire nasal cavity simply enlarge and adapt itself to the new arrangement, instead of sending off this elaborate and troublesome system of accessory sinuses? We have only to recall the picture of atrophic rhinitis to demonstrate mildly the inefficient drainage and humidification which would have been accomplished by such a cavity. And besides, the turbinated bones which are purposeful organs must be supported in their existing positions in order to preserve their efficiency.

This theory accounts for the fact that, in the case of the ethmoidal sinuses, "cells that arise from unlike meatuses never communicate with one another. Furthermore, a cell always communicates with the meatus from which it develops." It is

23. Schaeffer, J. P.: loc cit., pp. 177 and 207.

further suggested as the reason why the two frontal sinuses never communicate and that two cells of the same frontal sinus never fail to communicate.

The sphenoid sinus in fetal life lies anterior to the sphenoid bone. Even throughout infancy no portion of it is contained within the sphenoid bone. When finally it does enter the bone, about the fourth year, rapid growth of the sinus takes place, not dorso-ventrally, as might be expected were the sinus merely pushing its way into the bone, but laterally and cephalo-caudally.

In other words the development of this particular region at this time is up and down and crosswise, and not from back to front with the rest of the face. The orbits are separating; the structures of the neck, which are keeping pace with the lateral growth of the jaw and face, are separating the right from the left, and the locus of cleavage is that of the sphenoid sinuses.

The maxillary sinus begins as a pouch or evagination of the mucous membrane of the floor of the infundibulum ethmoidale, at about the seventieth day of fetal life. From the one hundredth day to term it grows in length from approximately 2 mm. to 8 mm.; in height, from .5 mm. to 5 mm., and in width from a mere slit to 4 mm. In other words, its growth tends toward length and height, not toward width, which follows the development of the face during the same period. It lies medianward of the orbit and does not occupy the adult position until the eruption of the permanent teeth and the full growth of the upper jaw. It is obvious therefore that when the tooth buds develop into teeth and forsake the maxillary bone for the mouth that a space must be left and that this space is the maxillary sinus.

Note also that the ostium of the maxillary sinus is in the middle meatus, the point of origin, and not the adult location of the antrum. It was from this point that the face-parts first receded pulling a pocket after them.

If this theory is to stand, similar cavities should be encountered in all locations in which like mechanics of development obtain. The necessary conditions were encountered in only one location, namely, in the temporal bone.

In the mastoid process cancellated bone is found at birth (as in the sphenoid bone). The so-called pneumatic mastoid is never present at birth, but develops gradually through childhood to adolescence. Here again is a cranium large in proportion this time not to the face but to the infant shoulders. Lines of muscle tension are parallel or converge from skull to shoulders. In the adult they diverge from above downward. As the individual grows a large mastoid process is required to give increased attachment and leverage to the muscles. Still the cranial surface of the temporal bone must remain fixed. It is another case of readjustment of opposite sides of a bony structure. Again there is the necessary connection with the nearest air-cavity, the middle ear, and again the appropriation of the lining membrane of that cavity.

ADDITIONAL EVIDENCE. The work of Wittmaack on the normal and the pathologic pneumatization of the mastoid bone[24] throws some light upon the irregularity of sinuses and their formation. Wittmaack contends that the normal mastoid process is a spongy bone structure until the end of the first year, a partly pneumatized structure until the fifth year and is completely pneumatized after that period. All temporal bones

24. Wittmaack: Über die Normale und Pathologische Pneumatisation des Schlaefenbeines. Jena.

which exhibit pronounced variations from the normal type, show signs of a past pathologic process—an otitis media neonatorum. He states further that inflammatory conditions of the mucous membrane of the middle ear during the first months of life, change the process of pneumatization to one of sclerosis, which corresponds to the first mechanical possibility mentioned, namely, that of filling the vacant spaces with bone. Wittmaack finds also that pronounced protrusion of the lateral sinus occurs in complete arrest of pneumatization, and only then. Is it not likely, therefore, that in a bone, the outer table of which is called upon to protrude and the substance of which has by a former pathological process lost its power of pneumatization, the inner table should follow the outer, as in this case of the lateral sinus? The protrusion of the lateral sinus is found only in pathologic pneumatization and furthermore the degree appears to vary directly with the extent of the inflammatory process.

The failure of some nasal sinuses to develop may well be upon a kindred basis.

Several apparently unrelated facts have been recalled which may have a bearing upon this theory and are worth mentioning:

There is first the occasional absence of one or both frontal sinuses. In this class are included also those cases in which the sinus is extremely small and confined to its original position *in the naso-orbital region*, where to all intents it remains one of the ethmoidal group. In most, though not all of the radiographs examined, in which the frontals were either absent or unusually small, the superciliary ridge was thick and the individual had "overhanging brows." Measurements of skulls and skiagraphs indicate that in these cases the brow has not grown

forward to overhang the face, but rather that the face, for some cause or other, has failed to grow out, and the conditions which create sinuses were not present.

Next to the absence of sinuses may be considered the extreme variations in their size, not only in individuals, but in the two sides of the same individual. If sinuses were functioning organs, or even vestiges of functioning organs, it should be expected that in company with other paired organs—eyes, teeth, kidneys, testes—they should be of fairly constant size in individuals of the same race, and still more so in both sides of the same individual. If however the sinuses are formed as a rift is made in a log by a driven wedge it is easy to see how a slight variation in the wedge, or a slight inequality in the elasticity of the wood, could result in a very large variation in the size of the rift. Thus minor variations in tension, due possibly to differences in the thickness of the bone, density, degree of ossification, or muscle stresses, would account for the wide variation in the size of the resulting cavities.

Skulls are frequently encountered in which the sphenoidal sinus of one side is rudimentary, and the sinus of the other side occupies the entire body of the sphenoid, necessarily crossing the middle line to do so.[25] This alone suggests that the mechanical requirements of the situation demand a pneumatization of the bone and that upon the failure of one sinus to develop (through any cause, say an early inflammatory condition, such as Wittmaack describes in the temporal bone), the other sinus is drawn in to fill the gap. (Note that the disparity in the sizes of paired sinuses occurs only in the contiguous ones where the process of substitution can obtain.) Such

25. Loeb, H. W.: The Cubical Capacity and Superficial Area of the Sphenoid, Maxillary and Frontal Sinuses. Ann. Otol., Rhin. and Laryn., 21:1073 (Dec.), 1912

variability and adaptability is characteristic of the purely structural elements of the body rather than of functioning organs.

Along with the absence and variation in size may be considered the enormous frontal sinus of the elephant already referred to. Here is a striking example of unusual facial development required by the muscle attachments of the trunk and by the tusks, tending away from a small and practically stationary cranial cavity.

Eckert-Möbius[26] is at least fundamentally in agreement with this theory. He states his conviction that the chief cause of the pneumatization of the mastoid process and of the facial bones is to be found within the bone itself. He feels further that the pneumatization of certain bones is due to the fact that they adjoin hollow spaces containing air. He assumes a "form-giving" power of the pneumatizing epithelium, and credits it with the primary pneumatization taking place in the undifferentiated embryonal tissue. He believes also that the constructive and destructive processes supply the stimulus for further extension of the sinus mucosa.

Galperin[27] suggests a somewhat similar developmental origin for the sinuses and describes in some detail the strains and stresses in the various parts of the skull which give rise to the various cavities. He attributes these strains solely to the pressures exerted by the chewing apparatus, which he quotes Black and Eckerman to have determined in women to be 20 kg. and in men from 25 to 100 kg.

26. Eckert-Möbius, A.: Fundamentals of the Problem of Pneumatization. Arch. f. Ohren, Nasen u. Kehlkopf, 124:43, 1936.

27. Galperin, J.: Anatomicmechanic Formation of the Construction of the Face Skeleton. Ztschr. F. Hals-Nasen-u. Ohrenh., 11:226 (June 2) 1925.

One is not constrained to adhere to a single theory as to what produces variations in the nose, for after all, the face and jaws are a mass of muscles so that the relatively plastic bones are constantly subjected to innumerable muscular pressures and tensions not to mention the more obscure primordial stresses which undoubtedly exist.

Still another explanation occurs to the author which he does not recall having encountered in the published writings. Accessory nasal air cavities are confined to terrestrial animals, and we find them developing as the species emerge from the water to live on the land. It is possible, therefore, that they serve the very important purpose of keeping the animal's head afloat and its nostrils out of water when it finds itself compelled to swim. The act of propulsion in the water is accomplished by motions similar to running, but the bodies of most animals in the water are completely submerged. Without the aid of these pneumatic cavities it would be difficult indeed for the animal to keep its head up.

It is significant in this connection that the animals mentioned above which have no sinuses, are otherwise adapted to long submersion and have no need to keep their heads afloat. Frogs, which float or sink at will, instead of having sinuses are equipped with an air chamber which can be filled or emptied as the occasion demands.

Into the small-sinus class falls the cat family, which is notoriously averse to water.

Animals with a heavy equipment of horns or tusks have large sinuses. This theory may explain the liberal endowment of the giraffe; one can well imagine that this awkward creature would have a bad time in the water unless its head were made to float.

It is fortunate for man that the large brain which has dispossessed the sinuses and rendered the head heavier than water enables him to *learn* to swim and keep his nose in the air.

Observers disagree as to the relationship between the shape and size of the sinuses and those of the face and the rest of the skeleton.[28, 29]

Barth[30] had an opportunity of examining sinuses and tracing the family history of 26 patients suffering from atrophic rhinitis. He also made roentgenograms of a total of 22 patients with this disease and studied its possible effect upon the development of the frontal sinus in man.

He concluded that the development of this sinus is not influenced by atrophic rhinitis.

However, since the pneumatization of the sinus takes place before atrophic rhinitis commonly begins, this is not surprising.

COMPARATIVE STUDIES OF SINUSES. A brief examination of the sinuses in various animals will be of interest in speculating upon their possible functions. An excellent resumé has been supplied by Nemours[31] who asserts that the first indication of a maxillary sinus occurs in the higher amphibians. In the more primitive forms in which the nasal cavity first makes its appearance, the sinuses are absent and the passages are not lined by ciliated columnar epithelium. Since water is

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28. Mündnich, K.: *Zum Pneumatisationsproblem der Nasennebenhöhlen* Ztschr. f. Hals-, Nasen u. Ohrenh., 43:5, 1937.

29. Mikhaloyts, N. I.: Correlative Variability of Volumes of Paranasal Sinuses. *Zhur. ush., nos. i gorl. bolez.* 15:45, 1938.

30. Barth, Hermann: Pneumatization of the Frontal Sinus in Atrophic Rhinitis with Ozena. Ztschr. f. Hals.,-Nasen-u. Ohrenh. 44:135, 1938.

31. Nemours, P. R.: A Comparison of the Accessory Nasal Sinuses of Man with Those of the Lower Vertebrates. Trans. Am. Laryng. Rhin. and Otol. Soc., 1931, p. 195.

taken through these passages, chiefly for the purpose of olfaction, olfactory epithelium predominates. In the higher forms such as the salamander and the frog, olfaction occurs through the air, and two types of epithelium are found. In general, ciliated columnar epithelium is found on the lateral side and olfactory on the medial. It is noteworthy that ciliated epithelium is not encountered so long as water is required to circulate through the nasal fossa, and conversely, as soon as definitive accessory nasal sinuses appear ciliated columnar epithelium is the rule.

The marsupials with one exception are without sinuses.

In mammals the one constantly present sinus is the maxillary. It is invariably developed from the sulcus above the maxillary turbinal corresponding to the middle meatus in man.

In many of the macrosmatic animals the outline of the maxillary sinus is somewhat deranged by the convolutions of turbinated bones covered with olfactory end organs. Here the nasal cavity and the walls of the maxillary sinus are continuous.

Subdivisions of the sphenoid sinuses often correspond to a similar division of these sinuses in some of the lower animals, in which the ethmoidal turbinals extend into the sphenoid cavities, producing septa.

Similarly Ingersoll[32] thinks that ridges sometimes found in the lateral wall of the maxillary sinuses represent the rudiments of ethmoidal turbinals which in some animals are attached to the lateral walls of these sinuses.

32. Ingersoll, J. M.: Some Points in the Comparative Anatomy of the Nose and the Accessory Sinuses which Account for the Variations in These Structures in Man. Trans. Amer. L. R. O. Soc., 28:162, 1922.

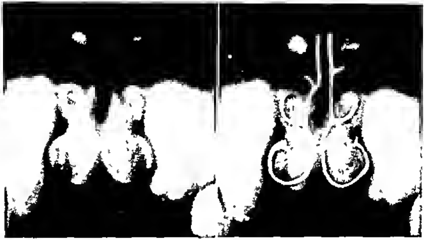

Fig 17. The laminagraph, left, shows that the breathing channels in the living are very narrow. On the right a diagram has been superimposed to indicate these air passages (Courtesy Dr. Sherwood Moore and the Mallinckrodt Institute.)

CUBIC CAPACITY. Braune and Clasen[33] measured the cubic contents of the nose and the sinuses as follows: A head was sectioned behind the choana and imbedded face down in such a support that the nostrils were sealed without compression. The nasal fossae were now filled with wax, after which the head was cut sagitally so that the wax could be removed and its mass determined. The sinuses were treated similarly. Naturally the results varied considerably in different heads, the average per nasal chamber being 17.1 cc. or 34.2 per nose. The total capacity of the sinuses varied from 37.1 to 59.6 cc. The proportion between the nose and the sinuses in each of three heads was as 2 to 3; in the fourth head it was 10 to 9. They computed the total air exchange of all

33. Braune, W. and Clasen, F. E.: Die Nebenhöhlen der Menschlicher Nase, etc. Zeit. für Anatomie und Entw. 2:1, 1896.

the sinuses at 1.8 cc. provided that a negative pressure of 60 mm. H_2O could be attained in the nose by the inspiration.

The capacity of the nasal chambers as determined by Braune and Clasen in the cadaver is almost double that found by the author in the living. This is to be expected unless special means were adopted to preserve the turbinated bodies in their normally distended form, of which they make no mention.

STUDIES OF THE OSTIA. Myerson,[34] VanAlyea[35] and Simon[36] in separate publications have studied a total of 379 maxillary ostia.

To these Myerson added 170 clinical observations. He points out that its three dimensions are defined by the encroachments of its bony confines, and that the relationships between the ostium, the uncinate process and the infundibulum determine its availability for irrigation. He emphasizes the observation of Gosseln[37] that the plane of the maxillary entrance is not always vertical, and that while the vertically placed ones are easily accessible, the horizontal are usually not.

Myerson's drawings illustrate the fact that the maxillary ostium is not a flat opening, but actually a tube of some depth the axis of which is sometimes angulated as much as 45 degrees.

34. Myerson, Mervin C.: The Natural Orifice of the Maxillary Sinus. Trans. of the Amer. Laryng. Assn. (June), 1931; Arch of Otolaryng., 15.80 (Jan.), 1932.

35. VanAlyea, O. E.: The Ostium Maxillare. Arch. of Otolaryng., 24.553 (Nov.), 1936.

36. Simon, E.: Anatomy of the Opening of the Maxillary Sinus. Arch. Otolaryng., 29.640 (Apr.), 1939.

37. Gosseln: Sur l'orifice du sinus maxillaire. Compt. Rend. Soc. de biol., 3:53, 1851.

VanAlyea finds the ostium accessible to cannulation through the nose in 54.6% of the cadavers examined. In about 20% the anatomical structures were such as absolutely to prevent contact with the maxillary ostium. "The breaking down of an obstructing uncinate wall, puncture through this wall or removal of a portion of an over-hanging middle turbinate or ethmoid bulla would have to be considered if the ostium were to be reached."

Simon dwells upon the importance of the depth of the ostia, which he found in 82.7% of his specimens to be canals of 3 mm. or more in length, the average being 5.55 mm. In contradistinction to this *all* but one of *16* accessory openings were simple fenestra.

"The maxillary ostium may be round, but as a rule is either oval or elliptical. In a series of 110 cases examined by [Schaeffer] it had a great range of dimensions, varying from 1 to 22 mm. in length and from 1 to 6 mm. in width. In cases where the ostium reaches considerable size it may entirely replace the lateral wall or floor of the infundibulum ethmoidale, thus forming a long slit-like communication between the maxillary sinus and the infundibulum ethmoidale."[38]

A word regarding the sphenoid ostium:[39] The sphenoid mucosa is characteristically thin, its tunica composed chiefly of parallel elastic elements laid closely together and bound firmly to the underlying bone. It contains very few glands. The nasal mucosa, on the other hand, is many times thicker and is permeated with vascular channels and glandular elements.

38. Schaeffer, J. P.: The Nose, Paranasal Sinuses, Naso-Lacrimal Passageways, and Olfactory Organ in Man. Blakiston's Son and Co., Phila., 1920, pp. 125-129.
39. Proetz, A. W.: "The Minute Anatomy of the Sphenoid Ostium." Transactions of the Amer. Laryng. Assoc., 55:125, 1933.

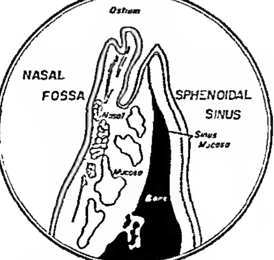

Fig. 18. Diagram showing a section of the lower margin of the sphenoid ostium, to demonstrate the relative thickness and the component parts of the nasal and the sinus membranes. The expansile elements are chiefly on the nasal side, and do not cross the bony margin into the sinus.

The two sheets of mucosa do not lose their identity at the ostium, and do not merge, but lie side by side until they reach the edge of the ostium, the only tissue which passes uninterrupted through it being the epithelial layer. The underlying bone comes to a sharp edge, around which no other structure can be seen to pass, and against which no structure can therefore impinge in case of swelling.

The tunica propria of the sinus can scarcely be said to enter into the formation of the ostium at all, as it terminates abruptly somewhat short of the margin. The ostium lining is thus a

part of the nasal mucosa which exhibits two or three small folds just at the opening, and which is here supplied with more than the usual number of mucous glands and venous spaces. The connective tissue elements are loosely arranged.

No nerve elements of any consequence are found. A few fibers are encountered, usually in close relation to the arterioles, but they are not large enough or so placed that engorgement of the vessels or edema of the tissues brings them under pressure against bone, especially against the bone margin of the ostium.

In so far as one may be permitted to deduce function from structure, the following suggest themselves with a reasonable degree of likelihood, at least in the case of the sphenoid ostium:

1. The connective tissue stroma and the intercellular spaces are so arranged that swellings probably take place into the nose and into the sinus respectively, and that only extreme tension can cause the tissues to encroach upon the ostium in such a way as to close it.

2. That in case of inflammation the nasal side of the ostium expands much more than the sinus side because of (a) the loose arrangement of tissues, (b) the disposition of the blood spaces and (c) the location of the folds and furrows in the mucosa.

3. That considerable engorgement or actual hyperplasia is required to close the ostium completely.

4. That the ostium, as such, is probably not involved in the causation of headache.

5. That the surgical protection of the ostium is important.

6. That since the ostium is composed chiefly of nasal, and not sinus, elements and is supplied chiefly by nasal arteries, application of constrictors, such as ephedrine, to the neighborhood of the ostium should usually suffice to open it.

VISCOSITY. In connection with the purely mechanical problems of nasal structure, one may profitably examine the phenomena of viscosity as they apply to the nasal fluids.

In gases, liquids and plastic materials the term viscosity is applied to the friction between the component molecules of the substance as they pass over one another when changes in the shape of the mass occur. Mucus and the various exudates commonly encountered in the nose may vary widely in their compositions and in their viscosities. The latter are usually high, as compared with the viscosities of blood plasma and the transudates. The sinus contents being rich in mucin, their surface tension is high, and globules form readily.

One must not conceive of pus in a sinus as being necessarily a thin fluid which readily seeks its lowest level. Instead, it often clings tenaciously to the walls. Changes in the posture of the head may not cause it to shift its position in the sinus unless they are maintained for some time. When patients whose nasal fossae are literally filled with pus lean forward, the pus does not escape from the nose as does, for instance, the thin fluid of hyperesthetic rhinitis. No more does the momentary shifting of the patient's head during the application of suction bring about a readjustment of the secretions within the sinuses sufficient for effective evacuation.

The viscosity of a substance is measured by the tangential force on a unit area of either of two horizontal planes at a unit distance apart required to move that plane with unit

velocity in reference to the other plane, the space between being filled with the viscous substance.[40]

The ratio of the force required to move the one surface parallel to the other, to the velocity of such motion (or "shear") is known as the coefficient of viscosity. It is expressed by the symbol η.

$$\eta = \frac{F \text{ (force)} \times S \text{ (distance between faces)}}{V \text{ (velocity)}}$$

It follows that in the case of fluids lying on inclined planes, such as secretions in sinuses, the value of V is low where the coefficient of viscosity is high, as the moving force F is limited to the weight of the mass itself.

In subacute inflammations, and still more in chronic ones, exudation is slow, and the coefficient of viscosity of the secretion high. The movement of the mass under such conditions is that of a semisolid rather than a liquid.

The movement of a thick stream making its way through an ostium devoid of cilia is not unlike that of globules of an emulsion passing through capillary tubes. The center of the mass moves at the highest velocity, the periphery scarcely at all.

Such streams move slowly. Sometimes their surface tensions are so high and their components so cohesive that they finally emerge from the sinus in a globular mass which retains its contours in the nose, and falls back into the pharynx, to the great consternation of the patient.

OSMOSIS. Of the osmosis of colloids, as it affects nasal problems, only this need be said: that upon it depends the nature of the secretion within the sinuses, and to some extent

40 Bingham, C.: Fluidity and Plasticity, 1922.

its fluidity. Since colloidal systems (embracing both the protoplasm of the living membrane and the products of inflammation which accumulate upon it) are especially sensitive to electrolytes in solution,[41] it should repay us to inquire more closely into the action of salts in various concentrations particularly with a view to improving the conditions of drainage. Much emphasis has recently been laid upon the importance of isotonicity of solutions employed in nasal treatment.

The sense of smell is dependent also upon nasal structure, as will be shown subsequently. The relative size of the nostril and the choana, and the direction and shape of the nostril are all co-ordinated so as to carry the inspired currents into the olfactory area. In contradistinction to most other animals whose cribriform plates are vertical and lie at the back of the nasal chamber (Fig. 8), man's olfactory apparatus lies high up in the chamber. His anterior nares are accordingly horizontal and project their air streams upward. The turbinates do not enter into this effect.

41 Bayliss, Wm.: Principles of Physiology, 4th ed., 1924.

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CHAPTER IV

THE SENSE OF SMELL

HUMAN ENVIRONMENT—THE DECLINE OF OLFACTION—MACROSMATIC AND MICROSMATIC ANIMALS—CULTIVATED PERCEPTION — OLFACTORY MEMORY — ASSOCIATION—ACUITY—THEORIES OF OLFACTION—DISPERSION OF ODORS—THE OLFACTORY APPARATUS—THE ORGAN OF JACOBSON—THE OLFACTORY NERVE—OLFACTORY CENTERS—SMELL AND TASTE—CLASSIFICATION OF ODORS—OLFACTION AS A DIAGNOSTIC AID—OLFACTOMETRY—VARIOUS OLFACTOMETERS—"FRACTIONAL FATIGUE"—PAROSMIAS—ANOSMIA.

HUMAN ENVIRONMENT. Man's relationship to his environment is conditioned largely by a complex pattern of sight and sound. The conception of size and shape and color, of proximity and remoteness, of light and shade and emphasis which constitutes his whole picture of himself and his universe is dependent upon these two senses.

Texture, essentially a function of touch, is conveyed after sufficient preliminary experiences, to distant objects inaccessible to the tactile perception of the individual. It is no longer necessary for him to handle a piece of velvet or stroke the surface of a marble statue or test with his fingers the sting of the nettle in order to make him acutely conscious of these textures. Sight further brings to him books and pictures which carry abstract as well as concrete impressions—conceptions arising in another mind. Sound in the form of speech, of music, of gunfire conveys to him impressions of thoughts and objects far distant in time and space.

It was not always thus. This pattern, into which is woven only an occasional impression of odor, was at one time in our existence based largely upon olfactory, gustatory and tactile experiences. Man, in his ascent, found sight and sound of much more use to him than the more primitive senses, and with their development olfaction came to play an increasingly secondary rôle.

His erect posture, no doubt, had much to do with this. By and large the breathing animals of the earth live with their eyes close to the ground especially while feeding, or they live in environments of forest and jungle where vision does not give adequate warning of the more swiftly moving dangers. Herds feeding, for example, are restricted in their vision and are obliged to depend upon their olfactory sense to warn them of the approach of an enemy. Wild animals tracking their prey depend for their very existence upon a trail of olfactory impressions, and their sense of smell is keenly developed. These are the "macrosmatic" animals.

If one could experience the mental images of these animals, they would undoubtedly be very different from our own. Take a mouse, for example, foraging in the dark. He lives in a world of sounds and odors, modified only faintly by sights.

"There can be no doubt of the all-important part that smell plays in the life of the dog", observes McKenzie.[1] "Everyone is familiar with it, and yet we do not often stop to think what its meaning is for the canine brain and understanding. One of the mysteries that must, one would suppose, forever remain hidden from us is what aspect the world we both share

1. McKenzie, Dan: *Aromatics and the Soul*. Hoeber, New York, p. 34.

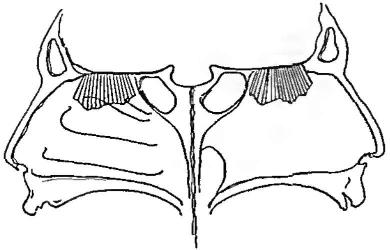

Fig. 19. Diagram to indicate the extent of the olfactory area in the human nose; on the left, the lateral wall; on the right the septum.

in company bears to this our closest animal friend. Who can tell what is passing through his mind as he sniffs at us? He can recognize his master by sight, no doubt, yet as we know he is never perfectly satisfied until he has taken stock also of the scent, the more precisely to do so bringing his snout into actual contact with the person he is examining. It is as if his eyes might deceive him, but never his nose."

Animals are divided into macrosmatic and microsmatic. The place which they occupy in the scale depends chiefly upon the extent and distribution of the olfactory nerve ends in the nose. While in man, for instance, who belongs to the microsmatic group, the area is restricted to a relatively small portion of the mucosa and this confined to the roof of the fossa, dogs and others of the macrosmatic group have highly

convoluted turbinals which increase the olfactory area manyfold.

The acuity of man's olfactory sense, or better the lack of it, is peculiar to the species rather than to the individual. Often this would seem open to doubt. First impressions would

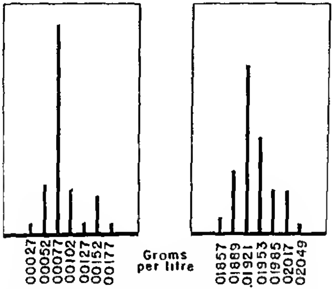

Fig 20. Typical graphs obtained in examining normal persons for the determination of the "minimum perceptible." The first chart is for coumarin; the second for phenol

suggest that certain people have a much keener sense of smell than others. Tests upon several hundred subjects do not bear this out. The above graphs are typical.

From these it will be seen that the great majority of recorded minimum perceptibles cluster about a norm. This was invariably true for some twenty substances tested, and indi-

cates that apparent variations are those of smell consciousness and association and not of actual acuity.

Cultivated Perception. It is also an accepted fact that particular olfactory perceptions can be cultivated. The housewife, for example, is acutely aware of the smell of burning food, the mechanic of a hot bearing. Persons trained for the purpose can distinguish minor olfactory variations. Tea, coffee and wine tasters and perfumers have this sense developed to an incredible degree. At the same time, the untrained individual is unable to identify many of the simplest odors. Blindfold tests show this.

Persons deprived of one of the senses develop the others excessively. This is true of the blind, and especially of the deaf-blind. Many of these persons can orient themselves fairly accurately through the sense of smell. Even in such cases it has been shown that the actual acuity of the sense perception is not increased but that the difference lies in the association and classification of smell impressions.

It is said that the sense of smell in animals is specialized, herbivorous animals being sensitive to the odors of plants and flowers. The carnivora on the other hand, whose sense of smell is so keenly developed for animal scents that they may track persons or other animals hours after a trail is left, either have no perception of the odors of plants, or ignore them.

Olfactory Memory and Association. The sense of smell is one of the very primitive developments of the race, and figures prominently in association and memory. A slight odor may recall to mind long chains of events and experiences which have taken place many years before o in childhood.

Some authors maintain that olfactory memory does not exist in the sense that we recognize visual and auditory memory; that is to say, that one cannot recall at will an odor which he has previously experienced. This may be true of certain individuals and, like most contentions regarding subjective impressions, is difficult of proof. However, there are few among us who will deny that they can readily conjure up the aroma of coffee, the smell of glue or the musty odor of a damp cellar. As in the case of smell perception, this also is probably dependent upon habit and conditioning.

Not only is the sense of smell a primitive one and developed early in the history of the race but it is highly developed in the young individual. Second only to gustatory stimuli the infant responds to odors, or at least to gustatory odors.[2] Stirnimann, who has observed the vasomotor and motor reflexes in new born infants is of the opinion that these young individuals have not merely the power of perception but of distinction between odors.[3]

ACUITY. Incredible feats of olfaction among the insects are recorded by Fabre, Lubbock and Forel. There is not room here even to abstract their writings, which are voluminous, but they are profitable reading to students of the subject.

The buzzard's sense of smell is so keen that he can detect the decomposing carcass of a mouse while soaring hundreds of feet above the earth.

It is significant that primates, spending their life in the jungle, have a keener sense of smell than man, although in

2. Ciurlo, L.: The Olfactory Function in the Newborn (Sulla funzione olfattoria nel neonato). Il Valsalva, 10:22-23 (Jan.), 1934.

3. Stirnimann, F.: Taste and Smell in the Newborn. Rev. franç de pediat., 12:453, 1936.

the higher types the sense is still not so keenly developed as in the more primitive ones. Odors which appeal to man are also pleasing to the gorilla.

The olfactory apparatus is sensitive to a much greater number of chemical substances than is the gustatory, also it is sensitive to a higher degree, responding to much greater dilutions. According to Parker and Stabler the olfactory organ detects dilutions of alcohol 24,000 times greater than those required to stimulate the organ of taste.[4]

THEORIES OF OLFACTION. The exact process by which odors are perceived is by no means well understood. Two principal theories exist: one that there is a chemical reaction between the particles of odorous substance emanating from the so-called "odorivector"; the other, the undulation theory, that waves of energy are communicated to the olfactory nerve endings much as light reaches the retina.[5]

The experimental data at hand tend rather to the former than to the latter, although, if indeed it be properly interpreted, there is evidence which seriously conflicts with both of them.

It is characteristic of the subtlety of the sense of smell that in this age of highly specialized knowledge of physiochemistry the true nature of odors is still not understood. In the midst of a universe which we are being taught to regard largely in terms of energy and vibration, there is much to attract one to the theory of physical rather than chemical stimuli in the perception of smell. These may be one and the same thing.

4 Parker and Stabler: On Certain Distinctions Between Taste and Smell. Amer. Jour. Physiol., Vol. 22, pp. 230-240.
5. Thompson, C. J. S.: The Mystery and Lure of Perfume. Lippincott, Phila., 1927.

In support of the purely chemical theory are the now famous experiments of Fabre and others with certain moths and beetles and with the macrosmatic animals. According to these investigators odor depends upon molecular diffusion of substances which are relatively volatile. Fabre is unwilling to compare the perceptive senses of moths to the sense of smell as man understands it. He finds it difficult to imagine a substance so diffusible that its emanations could be effective at the distances recorded in his experiments. This, he says, would be tantamount to "reddening a lake with an atom of carmine, to filling immensity with nothing."

McKenzie, who is inclined to accept this diffusion theory, points out that Fabre himself would have been likely to accept it had he been more familiar with the acuity of olfaction as it exists even in the human. "Vanillin", he states, "is perceptible by us as a smell when it amounts to no more than 0.000000005 grams in a liter of air; and we can perceive mercaptan, a substance with a garlicky odor, in a dilution of 1/460,000,000 of a milligram in 50 cu. cm. of air.

"What is this", he asks, "but 'immensity filled with nothing?' And yet we, even we, microsmatic though we are, can perceive that 'nothing.'"[6]

To explain his observations, Fabre hypothesizes vibrations similar to light. Even this does not satisfy him and he finally straddles his dilemma: "In its entirety smell would thus seem to have two domains: that of particles dissolved in the air, and that of ethereal waves."

Much that has to do with the sense of smell is based upon superficial observation, and facts are often unconsciously twisted to fit theories.

6. McKenzie, Dan: Aromatics and the Soul, Hoeber, N. Y., p. 39.

Bidder, for example, states that during quiet inspiration the air stream follows the shortest route from nostril to choana, that is, along the inferior turbinate, and since the inferior turbinate is obviously not supplied with olfactory epithelium, he sees this structure as a kind of vane to spray the air over the olfactory area.[7]

At a much earlier date, however, Charles Bell had already noted the constriction in the vestibule of the nose, which gave an upward direction to the air currents, away from the lower turbinates.

Heyninx[8] is the chief proponent of the wave theory of olfaction. He regards the olfactive waves as lying somewhere in the ultraviolet region of the spectrum. He supports his theory with the observation that by spectral analysis certain odoriferous substances in the gaseous state may be shown photographically to absorb some of the ultraviolet rays. He finds some relationship between the absorption bands and the nature of the odor, and also between the size of the pigment granules of the olfactory mucosa and the wave length of violet and ultraviolet light. He bases upon this a sort of resonator theory according to which various specific granules are activated by waves of specific length. The accuracy of his measurements has been questioned by McKenzie and others.

On the whole there is nothing, at least at this writing, to point toward a completely acceptable theory.

Dispersion of Odors. Means by which odors reach the olfactory nerve are two: convection and diffusion. Zwaarde-

7. Bidder in Wagner, R.: Handwörterbuch der Physiologie. Braunschweig, 2.920, 1844.
8. Heyninx, A. Essai d'Olfactique Physiologique. Vve. F. Larcier, Brussels

maker names a third, namely oral, producing gustatory odors; but it is difficult to see how this can be regarded as a separate class since it represents merely a combination of the other two. The odors which penetrate the nose through the nasopharynx during mastication and the swallowing of food obviously reach the olfactory area either by a diffusion of their odorivectors, or by means of small gusts of air resulting from the motion of the palate and the muscles of deglutition.

While the *evaporation* of *certain* substances in a quiet atmosphere undoubtedly reaches the nose by diffusion, still the actual smell impression is accomplished invariably by a slight sniffing and hence by convection. It is pointed out that odorous substances may be brought to the nostrils without producing any smell impressions, even when the diffusion is sufficient to produce slight tingling of the mucosa, as in the case of camphor. This may easily be simply a quantitative difference; during a sniff the air is projected against the membrane in eddies, and by virtue of the impingement effect (see page 129) many more odorous particles are brought in contact with the nerve endings than would reach them by diffusion alone.

Apparently to be perceived by the smell apparatus, a substance must be finely divided and air-borne. If the nasal cavities are filled with odorous solutions, there is a stimulation of tactile sense but olfaction does not occur.

Volatility plays a fundamental part in the distribution of odorivectors, and hence in their perception. Certain substances which are scarcely detectable when in watery solution, are immediately perceived when alcohol is added to the solution, although the odor of the alcohol itself may be very feeble.

Henry[9] found that the loss per second and per square millimeter of surface for certain highly odorous substances such as menthol, lavender and oil of bergamot was of the order of .000033 mg.

The amount of moisture present in the olfactory region is important. There must be sufficient to permit solution of the substances and not so much as to carry it off or to dilute it greatly.

Concentration plays a large part in the character as well as the intensity of the smell impression. It is well known that some odors which are pleasant in dilution are disagreeable and sickening when concentrated. It is also known that certain substances which are highly disagreeable in their concentrated state, modify the odors of other substances when added to them in extremely small quantities, and even contribute to their quality and permanence (civet, musk, ambergris).

THE OLFACTORY APPARATUS. Although the central apparatus consists of a score of nuclei, tracts and fasciculi, which is hardly surprising when one takes into account the complexity of smell impressions, still the peripheral organ in the nose, which records these impressions, is bafflingly simple. Unlike the perception apparatuses of the eye and the ear, the specific sensory epithelium in the nose is very primitive.

The epithelium of the olfactory region consists of three kinds of cells, the olfactory cells proper, the supporting sustentacular cells and small stellate basal cells. Serous glands, known as Bowman's glands, are found in the submucosa. The olfactory cells lie in the middle and the deeper layers of the epithelium. They are fusiform in shape, with a spherical

9. Henry, Charles: Les Odeurs. Conference of Mar. 14, 1891, Paris, 1892, p. 40 (cf. Zwaardemaker, p. 14).

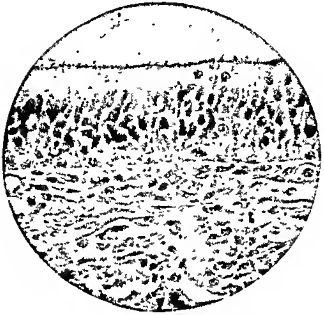

Fig. 21. Photomicrograph; Olfactory Epithelium. Man.

nucleus. A peripheral process, irregular in shape, reaches the surface of the epithelium between the sustentacular cells. At the surface it terminates in a bulbous end, upon which are numerous olfactory hairs. These project free in the nasal cavity. The central process of these cells is the axone, or olfactory nerve fiber.[10]

The cytoplasm of the sustentacular cells usually, though not invariably, contains a yellow pigment.

Impulses are conducted by the peripheral processes, or dendrites, to the bipolar cell bodies, thence by the central processes, or axons, to the olfactory bulb.

10. Read, Effie A.: Olfactory Apparatus in Dog, Cat and Man. Am. Jour. of Anat., 8:17, 1908.

Fig. 22. Photomicrograph: Mucosa of the human septum, showing the transition from the respiratory type of epithelium, left, to the olfactory type, right.

THE ORGAN OF JACOBSON. The organ discovered by Jacobson in 1811 and named after him was at first thought to moisten the oral cavity. It was suggested also that it might serve the function of discriminating between palatable and repulsive matters. Comparative anatomical and histological investigations lend weight to the belief that it is a vestigeal organ.

Where it exists in functioning form, it is part of an olfactory system complete in itself, comprising the vomeronasal organ, containing typical olfactory neural epithelium, its axons which constitute the vomeronasal nerves, and a central connection which is an accessory olfactory bulb, called the tuberculum vomeronasale.

To a comprehensive article by Pearlman[11] on the subject of this structure is appended a bibliography of 126 references. In spite of the attention which has been devoted to it this author still is forced to the conclusion that "The precise function of this curious olfactory organ is not known."

The vomeronasal nerve, which in the macrosmatic animals is an important part of the system, is not present in man, in whom the organ of Jacobson is very rudimentary.

The functions of the vomeronasal nerve and the nervus terminalis are likewise not understood. It has been suggested that they are vestiges of organs sensible to general chemical stimuli, and that their function has been largely supplanted by the more highly developed olfactory system.[12]

For an anatomical discussion of these nerves the reader is referred to Schaeffer (page 326).

THE OLFACTORY NERVE. The olfactory nerve filaments in each fossa issue from the foramina of the cribriform plate in two rows, a medial and a lateral. They are nonmedullated filaments and are about twenty in number. Collectively, they are known as the olfactory nerve. It was formerly thought that they constitute a plexus, but the researches of Effie Read have shown clearly that they remain discrete and that the netlike appearance is due to a clumping of the nerve bundles and to the arrangement of the surrounding connective tissue and blood vessels.[13]

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11. Pearlman, S. J.: Jacobson's Organ (organon Vomero-Nasale *Jacobsoni*): Its Anatomy, Gross, Microscopic and Comparative, with Some Observations as well on Its Function. Ann. Otol., Rhin. and Laryng., 43:739 (Sept.), 1934.

12. Herrick: Introduction to Neurology. Phila., 1916.

13. Read, Effie A.: Olfactory Apparatus in Dog, Cat and Man. Am. Jour. of Anat. Vol. 8, 1908.

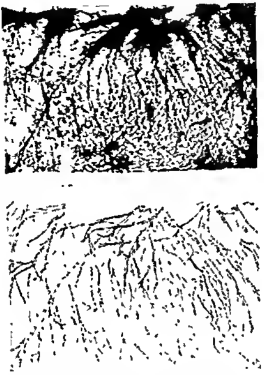

Fig 23. Olfactory nerve fibers, after Effie A. Read, who first demonstrated them to be discrete filaments and not a plexus.[14]

From the cribriform foramina these filaments pierce the cerebral meninges and enter the olfactory bulb, "there to synapse with the dendrites of the mitral cells in formations known as the olfactory glomeruli. The latter contain the first synapse in the olfactory pathway."[15]

14. From the American Journal of Anatomy, 8:17, 1908.
15. Schaeffer, J. Parsons: The Nose, Paranasal Sinuses, Nasolacrimal Passageways, and Olfactory Organ in Man, Blakiston, Phila.

OLFACTORY CENTERS. In man the communications between the olfactory bulb and the subcortical centers are inferior to those between the bulb and the cortex. In the macrosmatic animals the reverse is true. The olfactory nerve, unlike the rest of the sensory nerves, has no well-developed ganglion but a poorly developed communication with the subthalamic regions, and only indirect communication with the thalamus.[16]

Cajal regards the uncus as the chief olfactory center of the brain. This and the other parts of the gyrus hippocampus communicate closely with one another and with Ammon's horn and the fascia dentata which he regards as cortical olfactory centers. His conclusions are based upon anatomical studies; experimental work has to date proven ineffectual in demonstrating the olfactory centers.[17]

Many observations have been made of the olfactive disturbances of individuals whose brains at post mortem have yielded exceedingly conflicting evidence.

A great many central structures are, at least partly, involved with the olfactory function. A discussion of these anatomical structures does not properly belong in a work on physiology. It may be of interest, however, to enumerate them if only to emphasize the extremely complex relationships which exist. These may account in great part for the intimate associations between the sense of smell and a diverse series of bodily functions.

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16. Seydell, Ernest M.: *A Survey of Fact and Theory in the Field of Olfaction.* Trans. Amer. Laryng Assn., 1931, p. 167; Annals of Otol., Rhinol. and Laryngol., 40:472 (June), 1931.
17. Cajal, Ramon: *Histologie du aystem nerveux de l'homme et des vertebris,* Paris, 1911, Vol. II.

Schaeffer lists them as follows:

Olfactory lobe:

(a) Olfactory bulb.
(b) Olfactory tract.
(c) Olfactory trigone.
(d) Anterior perforated substance.
(e) Parolfactory area (of Broca).
(f) Subcallosal gyrus (peduncle of corpus callosum).

Olfactory Cortex and Accessory Parts:

(a) Uncus (gyrus uncinatus).
(b) Hippocampus (hippocampus major).
(c) Amygdaloid nucleus.
(d) Supracallosal gyrus, including the medial and lateral striae (gyrus epicallosus, indusium griseum.
(e) Dentate fascia (gyrus dentatus).
(f) Septum lucidum (septum pellucidum).
(g) Fornix.
(h) Fimbria.
(i) Mammillary body.
(j) Habenular nucleus.
(k) Thalamus (optic thalamus).
(l) Anterior cerebral commissure.
(m) Medullary stria of thalamus.
(n) Mammillo-thalamic fasciculus.
(o) Mammillo-peduncular fasciculus.
(p) Terminal stria of thalamus (taenia semicircularis).
(q) Habenulo-peduncular fasciculus.
(r) Etc.

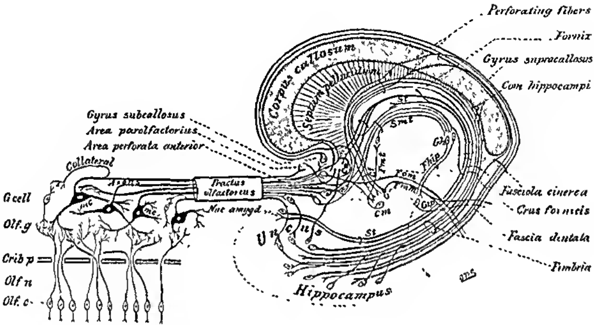

Fig. 24. Schema of the principal connections of the olfactory apparatus

G cell—Granule cell. *Olf g*—Olfactory glomeruli. *Crib p*—Cribriform plate. *Olf n*—Olfactory nerves. *Olf c*—Olfactory cells. *Ca*—Commissura anterior. *Cf*—Columna fornicis. *Cm*—Corpus mamillare. *Fmt*—Fasciculus mammillothalamicus. *Smt*—Stria medullaris thalami. *St*—Stria terminalis (semicircularis). *Gh*—Ganglion habenulae. *Gip*—Ganglion interpedunculare. *Fhi p*—Fasciculus habenulo-interpedunculare. *Fom*—Fasciculus olfacto-mesencephalicus. *Fmm*—Fasciculus mammillomesencephalicus.

From Schaeffer, J. P.: *The Nose, Paranasal Sinuses, Nasolachrymal Passageways, and Olfactory Organ in Man*, Blakiston Son & Co., Phila., 1920, by kind permission of Author and Publisher

It is pointed out by Schaeffer[18] that "the arrangement of the neurons and their mode of synapse within the olfactory bulb may lead to strong excitations in the olfactory centers even though the peripheral olfactory stimulation be feeble. Two or more olfactory nerve fibers may synapse with the dendrites of a single mitral cell, thus providing for the summation of stimuli in a single mitral cell."

SMELL AND TASTE. It is probable that the cortical center for taste lies in the hippocampal convolution near the uncinate gyrus, associated closely with the olfactory center.

Obviously it is extremely difficult therefore to dissociate one sense from the other even experimentally, since both the peripheral stimuli and the central connections are so closely associated, and the mental impressions and associations are so similar. Complicated experiments have been arranged whereby it has been shown that olfactory impressions have been produced by odorous substances intravenously injected.[19] The substances employed were neoarsphenamine and solutions of camphor and of turpentine oil. The nares were occluded with paraffin-soaked gauze in order to avoid direct stimulation. Of the patients with normal noses 14 detected the odor of the three substances. Patients who were anosmic due to atrophic rhinitis or other peripheral causes failed to detect any of the odors, although patients whose olfactory areas were merely occluded by polypi or inflammatory swellings were aware of the odors within six seconds, the time required for the substances to reach the olfactory region by the vascular route.

18. Schaeffer, J. Parsons: p. 338.
19. Bednár, M. and Langfelder, O.: Mechanism of Perception of Odors by the Hematogenic Route. Monatschr. f. Ohrenh., 64:1133 (Oct.), 1930.

Other odors smelled simultaneously did not interfere with the detection of the intravenous substances.

It is curious that the latter continued to stimulate following the application of cocaine to the olfactory area, while the ordinary sense of smell was impaired. The fatigue of the olfactory mechanism commonly noted with air-borne scents was produced also by the injected substances.

It was once the author's good fortune to examine a boy who was born without evidence of any nasal structure. This was a patient of Vilray Blair, who made a nose for the boy from a forehead flap, and demonstrated the case before the American Laryngological Association.[20]

There was no evidence of even a rudimentary external nose. The space ordinarily occupied by sinuses was shown by x-ray examination and at operation to consist of a solid mass of cancellous bone. The nasopharynx was a blind pouch into which the eustachian tubes opened.

This boy was carefully examined relative to his sense of taste and possible sense of smell. His intelligence was above the average, and his answers may be assumed to be accurate. He could differentiate things which, according to our accepted ideas, must have lain in the domain of the olfactory apparatus. For example, he could recognize coffee. Blindfolded he could identify by inhalation coffee held before his mouth. Similarly, he could recognize a flower. We were not able to determine whether the boy got any pollen into his throat or whether anything beyond the accepted odorivectors came off the flower. It was definitely demonstrated that he had im-

20. Blair, Vilray P.: Congenital Atresia or Obstruction of the Nasal Air Passages. Trans. Amer. Laryng. Assn., 53:241, 1939.

pressions beyond the salt, sweet, bitter and sour attributed to taste; so-called gustatory odors apparently resided in his nasopharynx. It was impossible to determine what may have been the position of his olfactory lobes, if indeed there were any, and the presence or distribution of any possible olfactory fibers.

CLASSIFICATION OF ODORS. Attempts to classify odors have been all but hopeless. Not only do the various classifications conflict in their details, but there is no unanimity of opinion as to which odors fall into which classes. There is no fine scientific gamut of scent comparable to the color spectrum. The two best-known classifications are those of Zwaardemaker and Heyninx. Probably anyone who reads them can suggest what to him seem logical improvements.

Zwaardemaker's classification: (1) Ethereal or fruity; (2) aromatic including as sub-classes camphorous, herbaceous, anisic and thymic, citronous, and amygdaline; (3) balsamic, with sub-groups floral, liliaceous, and vanillar; (4) ambrosial or musky; (5) garlicky, oniony, fishy and bromic; (6) empyreumatic (guaiacol); (7) caprylic (valerianic acid); (8) disgusting; and (9) nauseating.

Heyninx'[21] classification: (1) acrid; (2) rotten; (3) foetid; (4) burning; (5) spicy; (6) vanillar or ethereal; and (7) garlicky.

The perfumer's classification as typified by Rimmel's arrangement: (1) rose; (2) jasmine; (3) orange; (4) tube rose; (5) violet; (6) balsam; (7) spice; (8) clove; (9) camphor; (10) sandalwood; (11) lemon; (12) lavender; (13) mint; (14) anise; (15) almond; (16) musk; (17) ambergris; (18) fruit.

21 Heyninx, A.: Essai d'Olfactique Physiologique. Larcier, Brussels.

OLFACTOMETRY. The olfactory faculty received its proper share of enthusiasm for physiologic and psychologic research which spread over Europe in the second half of the eighteenth century. Writers of the day emphasized the importance of external impressions, in so much as they constitute the sole means of developing and directing the intellect; hence much attention was given to the special senses, as their avenues of entrance.

Knowledge of that period concerning the sense of smell found its completest expression in a monograph by Hippolyte Cloquet,[22] published in 1821.

Then for half a century nothing further of moment appeared.

ZWAARDEMAKER. In 1888, Professor H. Zwaardemaker of Utrecht invented his first olfactometer. In 1895 he published his great work "Die Physiologie des Geruchs"—a monograph of over 300 pages—which has since stood as the master work on smell.

Zwaardemaker investigated the subject exhaustively from many standpoints. He wrote as a physiologist, but included the anatomy, physics and chemistry of the subject. He submitted a classification of Linnaeus, but made important additions. He investigated a great variety of substances in an effort to determine the inherent processes of the smell function. He regarded these processes as a chemicophysical reaction between minute particles of the odorous substance (Riechstoffmoleküle) and the terminal nerve cells. He developed an

22. Cloquet, Hippolyte: Osphresiologie ou Traite des odeurs, du sens et des organes de l'Olfaction Paris, 1821.

olfactometer which superseded all previous devices, but which still left much to be desired and has not come into general use.[23]

No olfaction tests even today are in any way comparable in accuracy, and hence in the information they afford, to the tests employed by the ophthalmologist and the otologist for determining the acuity of sight and hearing.

As early as the middle of the nineteenth century, Valentin[24] described a method for measuring the minimal concentration of certain substances which would affect the smell apparatus —the "minimum perceptible." He allowed a measured amount of the substance to evaporate in an air chamber of known content, producing a known dilution. Further dilutions were made until the minimum perceptible was determined. This method was attacked by his contemporaries on the ground that it took no account of the adhesion of odoriferous particles, through condensation, to the walls of the successive containers. Furthermore, it is doubtful whether any method can be very accurate which depends upon the dilution of substances in masses of air, because of adventitious air currents which must be set up by the very act of smelling. The rate of inspiration also affects the result in such experiments, deep steady inspiration failing to produce olfaction which may be set up by a series of short, quick sniffs creating eddies and projecting an increased number of odoriferous particles through the olfactory fissure to the nerve endings. Valentin tried to overcome some of these difficulties by dissolving his substances in water, but the result was discouraging.

23. Zwaardemaker, H.: Ein verbesserter Riechmesser. Archiv. f. Laryngologie u Rhinologie, 3:367, 1895.
24. Valentin. Grundriss der Physiologie, p. 515.

Fröhlich[25] in 1851 mixed oils, spices and other aromatic substances with a measured amount of starch in such proportions that the intensity of the various odors was approximately the same. He then measured the distance at which the odors of the powders could be perceived by a blindfolded subject. He found, however, that his figures varied with the procedure employed in performing the test. He began at the nose and allowed his bottles of powders to recede until their odor was no longer perceptible. Then he reversed the process and allowed the substance to approach the subject noting the distance at which the first odor sensibility occurred. While he insisted that all his experiments were conducted with every precaution against draughts, still the motion of the test substance and the sniffing of the subject must have set up minor currents sufficient to disturb the odorous aureole about the mouth of the bottle. The distance at which one subject perceived the same substances on different occasions varied from 105 mm. to 160 mm.—a variation of 35 per cent.

Forty-five years later E. Aronsohn[26] conceived the idea of allowing a physiological sodium chlorid solution to flow through the nose, with the patient bending forward. He introduced small amounts of odoriferous substances into the water and noted the minimum concentration at which these could be perceived. Zwaardemaker and others took exception to this method on the ground that the solution does not come in contact with the olfactory areas. A bubble of air remains in the olfactory fissure; the sensation of smell is the

25. Fröhlich, R.: Sitzungsberichte der Mathematisch-Naturwissenschaftlichen Classe der kaiserlichen Academie der Wissenschaften. Vol. VI, 1851.
26. Aronsohn, E.: Experimentelle Untersuchungen zur Physiologie des Geruches, 1896.

result of evaporation into the air of the bubble, which introduces factors out of control of the operator.

As was pointed out earlier in this chapter proper smell perception depends upon the substance being air-borne, solutions of substances not being well perceived.

Fischer and Benzoldt[27] blew alcoholic solutions of mercaptan and chlorphenol from an atomizer into the air of their laboratory and computed the minimum required in order to

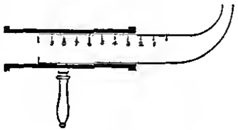

Fig. 25 Zwaardemaker's Olfactometer.

be detected by persons entering the room. The fallacy of this method lies in the probability of incomplete evaporation and in the introduction of alcohol, itself an odorous substance.

Other methods were devised from time to time, notably those of Dibbits[28] and Savelieff,[29] both of which required chemical apparatus too complicated for ordinary purposes, and which still permitted considerable error.

27 Fischer and Benzoldt: Zwaardemaker, H.: Physiologie des Geruchs. Leipzig, 1895, p. 83.
28. Dibbits, H. C.: Festschrift zu Donders' Jubiläum, 1888, p. 497.
29. Savelieff, N.: Untersuchung des Geruchsinnes zu klinischen Zwecken. Neurologisches Zentralblatt, 1893, No. 10, p. 340.

Jacques Passy[30] advocated the simple method of triturating substances in alcohol. He introduced one drop of these test concentrations into a liter flask and allowed it to evaporate, noting the minimum required for olfactory stimulation. This test has in its favor extreme simplicity, but like some of the others, it is at the mercy of air currents and employs an odoriferous solvent.

Zwaardemaker's olfactometer consists of two tubes, one fitting accurately within the other. The outer tube or cylinder

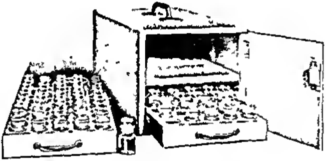

Fig. 26. Author's Olfactometer.

measures ten centimeters in length and eight millimeters in internal diameter. It is constructed of some odoriferous substance, such as wax or gutta percha, or of unglazed porcelain, which is impregnated with odoriferous solutions to be tested. The inner tube of glass, is longer than the outer, and the end which protrudes from it is adapted to the nostril. When this tube completely lines the outer, and air is inhaled through it, no odor is experienced. When, however, it is partly withdrawn, and a certain portion of the inner surface of the outer

30. Passy, Jacques: Comptes rendus des Seances de la Societé de Biologie. Jan. 30, 1892.

tube is exposed to the inspired air, olfaction takes place. These tubes are calibrated in centimeters, and the distance of withdrawal at which olfaction first takes place is noted. This apparatus also admits of some error. Zwaardemaker himself points out that slow, even respirations during which the substance from the outer cylinder has a better opportunity for evaporation yield a lower figure than do quick inspirations which permit of only a short exposure. He adopts slow respiration as standard in making tests with his instrument. Another source of error is the odorous aureole (Dunftwolke) which emanates from the outer surface of the outer cylinder and hangs about the opening of the tube. Zwaardemaker at first attempted to overcome this objection by glazing the end of the tube, but later he enclosed the entire apparatus in a glass jacket. Another troublesome feature, especially in general clinical use, is the necessity of soaking the cylinders in the solutions for an hour before the test is made. The growth of various organisms in the test solutions (and hence in the pores of the cylinders) is also the source of some error, in that they either render the solutions odorless or add an odor of their own.

Various improvements have been suggested, such as the substitution of porous paper as the material for the outer cylinder, through which the odorous substances reach the inner cylinder,[31] but none of them have been thoroughly satisfactory.

Hesse[32] succeeded in measuring the minimal perceptible for the fatty acids in milligrams per liter by a method which he

31. Henry, Charles: Olfactometre fonde sur la diffusion a travers les membranes flexibles. Comptes rendus des Seances de l'Academie des Sciences Feb. 9, 1891.

32. Hesse, Walter: Determination of Smell in Absolute Values. Ztschr. f. Hals-, Nasen . u. Ohrenh., 16:359 (Oct. 14th), 1926.

maintains can be applied to the clinical olfactometers, such as that of Zwaardemaker.

He later described a precision apparatus for determining odors in absolute values, which he records in terms of dilutions of 10^{-9}.[33]

The first requirements in an olfactometer are that it shall remain constant, and that it can be readily employed in the clinic. The instrument should yield qualitative, as well as quantitative data; it should be portable and always ready for use. In determining the form which it should take, the first consideration is simplicity. It is important to avoid, as far as possible, the personal element, which in spite of all precaution remains a great factor in the study of so purely subjective a phenomenon. It is desirable that no particular type of breathing should be required, and that no adjustments on the part of the patient or the operator be necessary. No such instrument is available at present.

AUTHOR'S OLFACTOMETER. For his own purposes the author employs a series of suitable bottles containing exact dilutions of certain carefully selected odorous substances. Held in a rack are a hundred bottles, arranged in ten rows, forming a square. Each row represents an odor, each bottle in the row an intensity. This olfactometer has the same faults as the others but offers a simple means of testing for acuity and variety with clinical if not laboratory accuracy. It exceeds in sensitivity most requirements.

One may vary it to suit his needs, but the selection of test solutions presents several problems.

33. Hesse, Walter: *A Simple Apparatus for Determining Smell Waves in Absolute Values.* Ztschr. f. Hals-, Nasen- u. Ohrenh. 19:248 (Dec.), 1927.

The diluent is of major importance. It must be odorless and nonvolatile; it must not be oxidizable by contact with the air, nor must it have any chemical effect upon the substances dissolved in it. For this purpose liquid petrolatum (light) Sp. G. .880 is employed.

In the selection of the odoriferous substances themselves, it was originally planned to employ a representative from each of Zwaardemaker's nine classes. This plan was modified in order better to represent certain chemical groups, the essential process of smell being regarded as chemical.

Ten substances were chosen, each representing a general class of compounds, and these were arranged in the order of their complexity, the simplest in row one. It is impossible, of eourse, in a portable apparatus to include even a small portion of known odors.

In the selection of these substances the following eonsiderations were borne in mind: First, characteristic odors were chosen, so that the patient, once having met one of them, should readily recognize it again. Second, substances not irritating to the mucous membrane in the required dilutions were employed, in order that the reaction be purely one of smell and have in it no element of common sensation. They are of low volatility, to insure stability. They are chemically stable, within reason, in order that contact with the air and the diluent shall not affect them. Lastly they are soluble in oil.

The following substances comprise the set:

A.—Iodoform. CHI_3 was chosen for its characteristic odor and relative stability, to represent the simplest organic halogen compounds. Minimum perceptible = gm. .0025 per

liter liq. petrolatum. Zwaardemaker's classification Vc— allyl odors.

B.—Methyl salicylate. $C_6H_4 < {OH \atop COOCH_3}$

represents the group of monohydroxybenzoic acids. Minimum perceptible = gm. .00297 per liter. Zwaardemaker's Group IIc— aromatic odors.

C.—Amyl alcohol, inactive ${CH_3 \atop CH_3} > CH\text{-}CH_2\text{-}CH_2OH$

This substance represents the tertiary alcohols. Minimum perceptible = gm. .00275 per liter. Zwaardemaker's Group VI ethereal odors.

D.—Xylol. $C_6H_4(CH_3)_2$, the third member of the benzol series, was selected for its relatively low volatility (B. P. 140°) in preference to benzol (B. P. 80°) and toluol (B. P. 110°). Minimum perceptible = gm. .01730 per liter. Zwaardemaker's Group VI empyreumatic odors.

E.—Nitrobenzol. $C_6H_5.\ NO_2$, represents the series of benzol substitution products in which one hydrogen is replaced by the radical NO_2. Minimum perceptible = gm. .03050 per liter. Zwaardemaker's Group IIe aromatic odors.

F.—Phenol. C_6H_5OH represents the group of phenols, hydroxyl derivatives of the benzols. Minimum perceptible = gm. .01921 (crystals) per liter. Zwaardemaker's Group VI empyreumatic odors.

G.—Guaiacol. Monomethyl pyrocatechol. $C_6H_4 < {OOH_3 \atop OH(o)}$

(Ortho-di-hydroxy-benzol + methyl.) Minimum perceptible = gm. .00302 per liter. Zwaardemaker's Group VI empyreumatic odors.

H.—Cinnamon oil represents a series of hydrocarbons of the formula C_nH_{2n-8} made up of a benzol residue and an unsaturated paraffin. Minimum perceptible = gm. .00106 per liter. Zwaardemaker's Group IIa aromatic odors.

I.—Eugenol. $C_6H_3C_3H_5(OH)$ (OCH_3) is one of a number of highly complex bodies derived from oil of cloves, catechin, vanillin and some related compounds. Minimum perceptible = gm. .00053 per liter. Zwaardemaker's Group IIb aromatic odors.

J.—Coumarin. $C_6H_4 < \begin{matrix} C_2H_2CO \\ O \end{matrix}$

This substance is one of the more complex members of the cinnamic group (H) above; its acid is coumaric acid (orthohydroxy-cinnamic acid). Minimum perceptible = gm. .00077 per liter. Zwaardemaker's Group III, balsamic odors.

In preparing an instrument of precision from these solutions the need of a standard unit of measurement early became apparent. This unit must be applicable to all instruments and all test substances alike. By the sense of smell alone it is impossible for the human being to determine accurately, or even approximately, the intensity of an odor, just as it is impossible for him to determine the candlepower of a light by merely looking at it. It is still more difficult to determine the relative intensity of two odors. It is necessary, therefore, to found this unit upon measurable and unvarying factors, alike for all instruments and unaffected by external influences.

It was found expedient and satisfactory to base the unit upon the concentration of the solution, a factor under perfect control, and to establish it as the minimum concentration of a substance in solution which can be perceived by a large num-

ber of normal individuals. This value the author expresses as one "olfact." It is expressed in terms of grams per liter. It is the value which has been referred to as the "minimum perceptible."

"Two olfacts" is applied to twice this number of grams per liter, "six olfacts" to six times, and so on, regardless of the apparent relative intensities of the smells of these solutions.

The term "olfact" as here used should not be confused with the "olfactie" of Zwaardemaker, to which it bears no relation. The latter is a term applied by the physiologist to the distance of withdrawal of the tube of his instrument. He used it to represent *surface areas* of gutta percha, wax, impregnated porcelain and other substances of which his cylinders were made.

It will be seen that a given substance may be more readily appreciable when dissolved in one solvent than in another, so that in expressing the actual gram value of the olfact in a given case it is necessary to specify the diluent as well as the substance—e. g., 1 phenol petrolatum olfact = gm. .01921.

In practice, after the instrument is once prepared, one is not interested for the purpose of the tests in the number of grams in solution, but in the proportion between what the patient can smell and one olfact, which represents what he ought normally to smell.

Thus smell expressed in olfacts represents acuity relative to the normal "minimum perceptible" under like conditions, and is therefore applicable to all instruments using solutions and allows automatically for variations in construction, size and type of bottle.

In order to arrive at the value of the olfact for each of the substances small amounts were accurately weighed and dissolved in measured amounts of liquid petrolatum, Sp. G. .880. One cc. of this solution was withdrawn and diluted ten times. A second dilution of ten to one was made, and another, and so on until the last solution proved imperceptible to a nor-

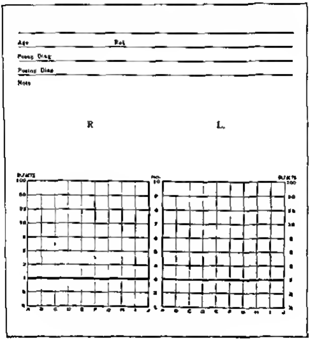

Fig. 27. Olfactometric Chart.

mal person. This person remained in an adjoining room and the solutions were brought to him to smell, in order to avoid errors occasioned by fatigue and by odors hanging about the room. This determined roughly the starting point.

Ten more solutions were prepared, the graduations in concentration this time being ten times as fine as those of the first

series. This series of dilutions was then given to a large number of apparently normal individuals to smell, and the peak for each substance was determined. A wide variation was expected here; it proved astonishingly small. Children under 14 years exhibited a slightly keener perception than their elders, but the results were found to cluster quite close to a mean.

CONCENTRATIONS. The apparatus contains in each row solutions of 1/4, 1/2, 1, 2, 3, 5, 10, 25, 50, and 100 olfacts, respectively. It was found that these graduations were sufficiently fine for ordinary purposes of record, and sufficiently coarse to minimize errors.

The appended table supplies the exact concentration in grams per liter of the solution in each bottle.

In making the tests a definite routine should be followed. A place is selected as free as possible from adventitious odors and other distracting influences. It is assumed that the patient's nose has been examined for mechanical obstructions. If crusts are present these should be washed out one hour before the test with normal saline solution. If obstruction is due to hypertrophy or edema it is permissible to shrink the inferior turbinates and the lower margins of the middle turbinates, provided that this is done with a cotton-wound applicator and not with a spray. Two per cent ephedrine solution should be used for this purpose. If epinephrin be used there follow in many noses reactions which interfere with the tests.

The patient should refrain from smoking for several hours before the test is made. The rack of bottles is placed out of sight of the patient. The bottles are held to the patient's nose to be sniffed, one nostril or both being open, as desired. The bottle is of the wide-mouthed, glass-stoppered variety. The patient may get as close to it as he likes; he may sniff or breathe

TABLE SHOWING CONCENTRATION OF VARIOUS SOLUTIONS EMPLOYED IN THE OLFACTOMETER.

IN GRAMS PER LITER OF LIQUID PETROLATUM.

Olfacts	Iodo form	Methyl Salic	Amyl Alc	Xylol	Nitro-benzol	Phenol	Guaiacol	Cinnamon	Eugenol	Coumarin
¼	.00060	.00074	.00069	.00432	.00762	.00480	.00075	.00026	.00013	.00019
½	.00120	.00148	.00139	.00865	.01525	.00960	.00151	.00053	.00026	.00038
1	.00250	.00297	.00275	.01730	.03050	.01921	.00302	.00106	.00053	.00077
2	00500	.00594	.00550	.03560	.06100	.03842	.00604	.00212	.00106	.00154
3	.00750	.00891	.00825	.05190	.09150	.05763	.00906	.00318	.00159	.00231
5	.01250	.01485	.01375	.08650	.15250	.09605	.01510	.00530	.00265	.00385
10	.02500	.02970	.02750	.07300	.30500	.19210	.03020	.01060	.00530	.00770
25	.06250	.07425	.06875	.43250	.76250	.48025	.07550	.02650	.01325	.01925
50	.12500	.14850	.13750	.86500	1.52500	.96050	.15100	.05300	.02650	.03850
100	.25000	.29700	.27500	1.73000	3.05000	1.92100	.30200	.10600	.05300	.07700

deeply; if he can detect an odor at all, the test is recorded as positive. Any slight error which might arise through the over-concentration of residual air in the bottle is avoided by filling it almost to the glass stopper.

The test is begun with the weakest solution in row 1—that representing ¼ olfact—and the stronger solutions follow in order until the subject detects an odor.

If the initial trials are made with the stronger members of the series instead of the weaker, fatigue may interfere with the accuracy of the record.

This proceeding is followed with each of the succeeding rows.

The olfactory organ can experience an odor too weak to be identified.[34] Frequently there is a difference of several olfacts between the "minimum perceptible" and the "minimum identifiable."

A few precautions are necessary to the accuracy of the tests: the glass stoppers should never be laid down or allowed to touch anything but the bottle; not more than one bottle should be out of the rack at a time; there should be no odor of tobacco or soap on the operator's hand.

It is well to fill one bottle with oil containing nothing in solution, in order to check subjects who maintain that they smell all test bottles. This sometimes occurs because the reflection of air from the bottle into the nostrils is interpreted as smell.

It is questionable whether olfactory impressions can be separated for purposes of study, so as to test individually the acuity of tracts involved.

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34. Passy, Jacques: Comptes rendus des Séances de la Societé de Biologie. Jan. 30, 1892.

It was observed long ago that the olfactive apparatus, at least in man, is peculiarly prone to fatigue. Zwaardemaker[35] plotted fatigue curves (ermüdungs-curven) for several odors. (He and others regarded odors as having "specific energies.")

In order to determine whether or not the whole smell apparatus is concerned with each olfactory impression, the author has utilized the fatigue phenomena.

Fractional Fatigue. Two solutions were prepared in suitable wide-mouthed bottles.[36] The first was a strong solution of an odorous substance, A. The second was a similar solution of A, to which a small amount of a second test substance, B, was added. The proportion was such that A in the solution completely overpowered B, which could not be detected by smelling. Accordingly, both bottles smelled wholly of A although the second bottle contained some B.

The first bottle (pure A) was applied to the nose and smelled for three to eight minutes, in order to fatigue the nerve to odor A. It was found at the end of this time that when the second bottle was again smelled, the odor of B was quite apparent.

This indicates that in some way the smell apparatus deals separately with various odors. Whether certain tracts become fatigued or whether specific components of the olfactory pigment cells become exhausted, we do not know. Supporters of the "undulatory theory," which credits the pigment with a large part in the smell function, adhere to the latter view. Until the exact nature of olfaction is understood, the causes of the fatigue phenomena must also remain unexplained. At least

35. Zwaardemaker, H.: Physiologie des Geruchs, Leipzig, 1895.
36. Proetz, A. W.: "Fractional Fatigue" of the Olfactory Apparatus, Arch. of Otolaryng., 1:638, 1925.

it is known that certain elements of the smell apparatus can be physiologically separated from other elements.

The experiment may be reversed by interchanging the concentrations of A and B, using B as the exhauster.

The phenomenon is much more pronounced with some substances than with others, notably aromatic volatile oils, such as peppermint, anise, clove and cinnamon. It can be produced as well by tasting the solutions (gustatory odors.) The best concentrations and combinations to obtain the effect vary with different persons.

Attempts have been made with indifferent success to localize brain lesions in the region of the complex olfactory apparatus by means of acuity tests. Beyond mere lateralization the results of such tests are questionable. One of the chief hindrances is the fact that the sensorium of the patient to whom these tests are most applicable is often clouded sufficiently to invalidate his responses.

Elsberg[37] reported several cases in which he was able to localize frontal lobe tumors, using coffee and citral as olfactory test substances, and believes, that the fatigue characteristics of the affected side may be diagnostically helpful.

He showed that there is a summation of impulses when stimuli reach both olfactory nerves, and also a somewhat lesser summation of impulses when the olfactory receptors of one side of the nose are stimulated by an odor, and those of the other by air.

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37. Elsberg, C. A.: Sense of Smell: Localization of Tumors of the Frontal Lobe of the Brain by Quantitive Olfactory Tests. Bull. Neurol. Inst. N. Y., 4:535, 1936.

PAROSMIA. Irritation and partial or complete degeneration of some of the peripheral fibers or portions of the central tracts may result in parosmia or distortion of smell impressions. The patient is beset by imaginary odors. These may arise spontaneously when no odorous substance of any sort reaches the nose; or they may take the form of false impressions when such stimuli are present. Food and drink assume strange odors, usually unpleasant. Even faint scents may be interpreted as smoky or ammoniacal. One patient complained that his hands had a disagreeable odor and washed them repeatedly, which only aggravated the trouble.

This cacosmia must be carefully distinguished from a veritable putrefactive odor arising from teeth, tonsils or sinuses.

ANOSMIA. Anosmia may result from any of several causes. The inflammatory process of infection may produce a degeneration of the olfactory mucosa including the terminal filaments of the olfactory nerve. Abnormalities in the structure of the airways, either spontaneous or surgical, may lead the air away from the olfactory area or may bring about a dryness in this region which first results simply in the inability to detect odors and later in an actual degeneration of the protoplasmic terminal filaments of the olfactory rods.

McKenzie[38] describes a partial anosmia which reminds him of color blindness. This may well be related to the fractional fatigue phenomenon.

Obstruction of the olfactory fissure by hyperplasia of the turbinates or by polyps may produce a transient anosmia, but removal of the obstruction is frequently disappointing, as the pressure existing over a period of time may have incapacitated

38. McKenzie, Dan: Aromatics and the Soul, p. 116.

the end organ by producing degenerative changes in the membrane. The application of zinc sulphate to the olfactory area in an attempt to immunize the patient against certain viruses, has resulted in impairment and loss of the sense of smell. Inhalations of certain corrosive chemicals such as osmic acid destroy the nerve endings.

Congenital anosmia is occasionally seen, especially in albinos. McKenzie mentioned the case of a negro who, gradually losing all his pigment, also became anosmatic, which suggested to him that the granules of pigment in the olfactory area may be essential to the perception of odors.

If the sense of smell remains a closed book, or at least one with many a page uncut, it is not for lack of interest nor of application. Bawden[39] went to some pains to gather the literature of the second half of the last century, and accumulated a collection of 885 titles.

39. Bawden, H.: A Bibliography of the Literature on the Organ and Sense of Smell. Jour. of Comparative Neurology, 11:1, 1901.

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CHAPTER V

THE RIGIDITY OF THE NASAL STRUCTURE

RIGIDITY AND AIR FLOW—NASAL CAPACITY CONSTANT—PRESSURE PHENOMENA IN RIGID CHAMBERS—AIR THE ONLY ELASTIC ELEMENT—LIMITATIONS OF GENERALIZED SUCTION.

The rigidity of the nasal framework plays so important a role in the scheme of nasal physiology, in the maintenance of function and in the progress of disease, and at the same time is so frequently disregarded in the plan of treatment, that a short excursion into its relationship to our subject may profitably be made.

RIGIDITY AND AIR FLOW. It manifests itself from several angles: first, inspiration through any but a rigid passage would be nigh impossible. It would be much as though the trachea were expected to function without its rings. The condition is exemplified by a deficiency of the alar cartilages, producing a collapse of the nares.

Further, rigidity is essential to a uniform and constant exchange of air in the sinuses. If the walls of these cavities were collapsible either large quantities of air, or no air at all would pass through the ostia with each respiration depending upon the position or the condition of the sinus walls and the ostium at the given moment.

Again, for the delicately balanced vasomotor control of the conchae to be at all effective it is necessary that the outer shell of the structure should maintain a constant total capacity.

Still other vital processes depend upon rigidity as will develop.

NASAL CAPACITY CONSTANT. For the proper conception of all those functions of the nose which deal with air currents, and for the intelligent application of treatment, which depends upon positive or negative pressures of gases and fluids, it is essential to bear in mind that the total capacity of an individual nose remains constant.

By this is not meant that it does not grow, or that through some pathological process its capacity may not be reduced. But from day to day and from minute to minute it is not variable. The mucosa may be spongy, edematous, atrophic, thick or thin, or it may be filled with polyps, but the wall behind it is bony and unyielding.

This means first that the passageway has a fixed maximum capacity.

It means also that any swellings or hyperplasias progress only *toward* the lumen, and produce for their respective volumes more obstruction than they would in a chamber whose walls are extensible and yielding.

It means further that ostia are made to stand apart from some adjacent structure, and thus maintain their patency.

But above all, and this is the condition almost universally overlooked, it means that when suction is applied and a vacuum produced within the sinus the contents are not simply extruded as they might be from a rubber ball whose walls collapse under pressure from without, or from a tube through which a current is set up owing to the presence of the second opening at the far end.

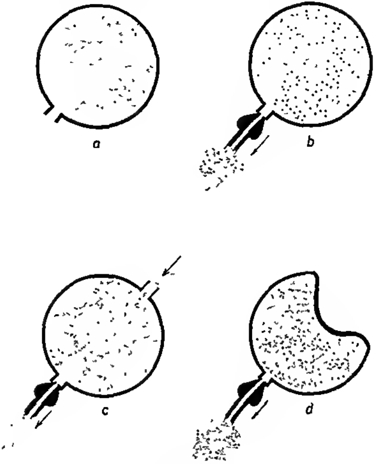

Fig. 29. Diagrams to demonstrate the effects of negative pressure applied to orifices in containers:

a) Air at atmospheric pressure in a rigid chamber with one orifice
b) Olive suction tip applied at orifice. Pressure in chamber reduced. Amount of air withdrawn is in direct proportion to reduction of pressure in chamber.
c) Rigid chamber with two orifices. Suction tip applied at one orifice. As pressure is reduced air enters second orifice at the same time to equalize it. Current traverses chamber.
d) Chamber with collapsible wall. As suction is applied and air is removed the flexible wall compensates Volume of air in chamber is reduced. Pressure not reduced.

The nasal sinuses correspond to a and b; not to c and d.

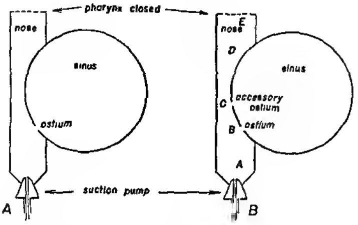

Fig. 30. Diagram to demonstrate that accessory ostia do not add to air exchange or permit currents to be set up when a suction tip is applied at the nostril.

A. Nasal chamber and sinus with one ostium. When the pressure in the fossa is reduced air is liberated from the sinus in proportion to the reduction of pressure. The conditions are those of a, Fig. 29.

B. Nasal chamber and sinus with two ostia. When pressure in the fossa is reduced, it becomes the same at A, B, C, and D. Since B and C are at the two ostia and at the same pressure, *no through-and-through current is set up from ostium to ostium.* Although there are two openings in this rigid chamber *the conditions are not those of c, Fig. 29.*

Pressure Phenomena in Rigid Chambers. The mechanics of a nasal sinus are almost precisely those of a tin can in which one small hole has been punched. Almost, but not quite, because into the sinus penetrate small blood vessels through which a hyperemia of the lining membrane can be produced, thus slowly bringing about a reduction in the capacity of the cavity and extruding some of the contents. Under such conditions it would remotely resemble the rubber ball or the tube rather than the tin can.

One cannot ignore entirely the small blood vessels in slowly progressive processes, such as vasomotor changes, infections, persistent complete obstructions of the ostia and kindred phenomena. In sudden pressure changes, such as respiratory fluctuations, percussions from diving, and treatments involving suction one must reckon without them. To these latter apply the mechanics and hydraulics of the tin can.

Air the Only Elastic Element. In such a system the single elastic element is the contained air. When positive or negative pressures are applied at the hole in the can, or at the ostium of the sinus the contained air is the one thing which can "give", the walls being rigid.

If such a container is partly filled with fluid, and negative pressure is applied at the opening, fluid is forced out by the pressure within, provided that the fluid overlies the opening when the pressure change occurs. But only so much emerges as corresponds to the volume by which the enclosed air is increased as a result of the reduction in pressure. The importance of this will be shown under the discussion of treatment involving pressure alterations.

The analogy of the can with a single hole, sometimes leads to the mistaken impression that an accessory ostium permits through-and-through circulation in the cavity, as occurs when a second hole is punched in the can. This would be true if suction were applied to one ostium alone, but negative pressure applied at the nostril or the choana is exerted at both ostia equally, hence no current is set up.

Limitations of Generalized Suction. As stated above, the volume of air exchanged corresponds exactly to

the amount of expansion or contraction of the contained air so that under clinical conditions this is extremely small.

A reduction of one-fifth of an atmosphere pressure is ordinarily well tolerated by the mucosa. Much in excess of this may be expected to be followed by hemorrhage which need not be evident, as it may remain submucosal. When infection of the hematoma occurs serious complications follow.

The best that can be expected of "massive suction" (i. e., suction applied via the nostrils to the nose at large in contradistinction to suction through a cannula) is that it frees the ostia themselves of material which may be momentarily occluding them, and draws it into the nose where it can be seen for diagnosis.

In certain special locations rigidity is of the utmost importance. Beneath the middle concha, for example, where the openings of the sinuses are in close relationships to other structures, and where these openings themselves may be tortuous passages it is essential that the framework be fixed, and the membrane thin. The multiplicity of troubles which arise when these conditions are temporarily upset by engorgement or edema and which led Ballenger to dub the region "the vicious circle", are evidence of this.

CHAPTER VI

AIR CURRENTS IN THE NOSE

INSPIRATORY AIR PATH — EXPIRATORY AIR PATH—THE NOSTRIL—THE NASAL AXIS—DIVERSE OPINIONS CONCERNING PATHWAYS—AUTHOR'S EXPERIMENTS—ADVERSE EFFECTS OF ADVENTITIOUS AIR JETS—IMPINGEMENT EFFECT OF CONSTRICTIONS — HILDING'S OBSTRUCTION EXPERIMENTS—AIR CURRENTS IN THE SINUSES.

If one would study the literature dealing with the pathways of air currents in the nose he must turn back to the '80s and '90s. In those decades a dozen American, English, French and German authors made reports which were by no means in agreement. Others writing at the present time have succeeded only a little better, although the points of difference now are relatively minor ones.

INSPIRATORY AIR PATH. According to Goodale, Lambert Lack,[1] Paulsen, Zuckerkandl and many others, and for that matter according to Galen, the stream of inspired air does not pursue a straight course from nostril to choana, but passes, in the main, in a wide curve beginning at the nostril, extending through the olfactory fissure and ending in the choana, thus practically avoiding the inferior meatus. Small eddies curl (1) against the face of the sphenoid, (2) down over the inferior turbinate, and (3) down in the vestibule. "Hence", says Lack, "nasal stenosis may be complained of if the middle

1. Goodale and Lambert Lack: Cf. Thomson, Diseases of the Nose and Throat. 3rd Edition, Appleton & Co., London, 1926, p. 7-8.

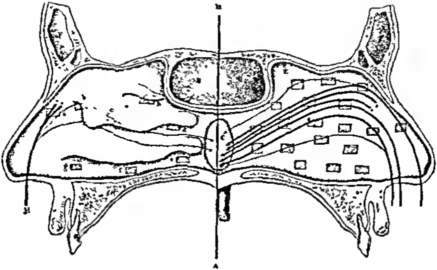

Fig. 31. Paulsen's diagram of the inspiratory nasal air currents, determined by means of ammonia fumes and litmus paper. Thickness of the lines indicates the relative amounts of flowing. (From Zwaardemaker, Physiologie des Geruchs, Leipzig, 1895.)

meatus is blocked, even when there is a free airway below this level."

This pathway is defined by the direction of the anterior nares, by the vault of the nose and by the opening of the choana which is wider than the nostril.

EXPIRATORY AIR PATH. These three structures determine the course of the expired air current as well, so that it follows much the same curve on its way out, except that this time some of it enters the middle meatus. Now the inlet (choana) is larger than the outlet (naris) and certain eddies are set up.

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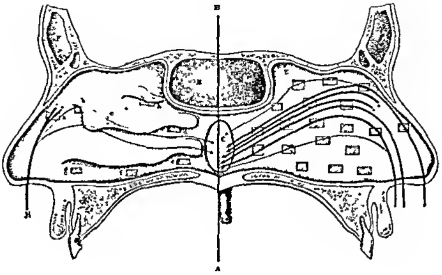

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The principal one of these eddies occupies practically the entire nasal chamber. The air having traversed the vault of the nose, and encountering some resistance at the nostril, divides. Part of it leaves through the nostril, the remainder whirls backward through the inferior meatus, rising to merge with the current from the pharynx above the choana, which impinges upon the margin of the posterior tip of the middle turbinate where part of it is diverted into the middle meatus.

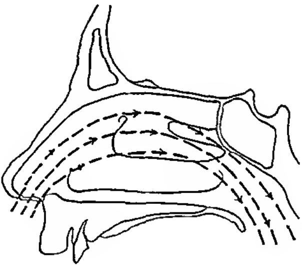

Fig. 32. Inspiratory air currents in the nose.

To put it briefly, both inspiratory and expiratory currents pass in a high curve through the nasal chambers, but *only the expiratory currents enter the meatuses.*

THE NOSTRIL. The nostril, which is the most constricted part of the system, alone determines the principal characteristics of the stream just as the nozzle of a garden hose directs

and shapes a spray of water. The rest depends upon the shape of the chamber. The turbinates, which are streamlined under normal conditions, have scarcely any deflecting influence upon the currents, although they play an important part in the valve action of the nose.

Nasal air currents are obviously the result of the simple physical characteristics of the fossa and deviate in no way from what may be expected.

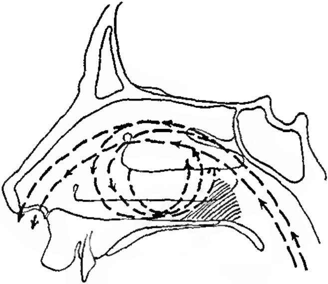

Fig. 33. Expiratory air currents in the nose.

Most authors are agreed as to the inspiratory pathways described above. There is diversity of opinion as to the expiratory pattern. This is to be explained in part by variations in the individual noses studied, and by the shortcomings of experimental mannikins. For the foregoing description of the expiratory currents, the author has fallen back upon his own

observations (see page 123) but now outlines in some detail the experiments and conclusions of a number of other observers.

Sternstein,[2] by means of a system of manometers, determined the resistance which air encounters in its passage through the airways. The measurements were made independent of voluntary nasal breathing and were based upon currents artificially induced.

In normal noses it was low, as might be expected, and fairly uniform. Shrinking these noses resulted in a reduction of 35 per cent. Partial nasal obstructions resulted in an increase of resistance of the order of 75 per cent.

The nozzle effect of the naris was, according to Zwaardemaker, first noted by one Charles Bell (probably Sir Charles Bell who contributed to the literature in the 1820s). The point of maximum constriction he describes as being about 1 cm. from the external orifice.

This observation has been clinically verified. Surgical alteration of the size and direction of the external nares has relieved frontal headaches and anosmia in selected cases and has reduced the number and intensity of colds, presumably by eliminating the concentration of inspired air currents and distributing them in a physiological manner.[3]

Whether by design or by accident, and there is little of the latter in nature, the principal axis of the anterior naris is in the young child relatively horizontal, and projects the air

2. Sternstein, H. J.: Nasal Obstruction in the Adult: A Quantitative Study. Arch. Otolaryng., 25:442 (Apr.), 1937.
3. Cinelli, Albert A.: Alterations in Nasal Function Due to Anatomic Variations of the Nares. Arch of Otolaryng., 31:53-64 (Jan.), 1940

stream backward into the low nasal fossa. With the development of the nose into the adult proportions the axis of the naris approaches the vertical and the air-stream is projected into the vault of the nose which is now high enough to receive it.

Classical observations upon nasal air currents and pressures were made by Braune and Clasen[4] in 1876.

In the decade preceding this work, numerous Germans displayed great interest in nasal air currents. They vied with one another in discovering small eddies here and there, and minor constrictions of the air passages which were said to affect the acuity of smell by changing the direction of inspired air.

DIVERSE OPINIONS CONCERNING PATHWAYS. Disagreement among early writers was often upon purely theoretical grounds, and upon experiments which today are not wholly convincing, as for example, the following from Hartz:[5] "Normally the expired air is under positive pressure and is completely saturated with moisture of blood temperature and contains CO_2 gas, and is 11% more voluminous than the inspired air. Unlike the negative air currents of inspiration, it does not rise, but chooses the path along the floor of the nose, there being no rarefied air currents to deflect it.

"Experiments appear to corroborate the pathway. A particle of wool placed in the middle and inferior meatus yielded readily by a forceful expiration from the lower, but with difficulty from the middle meatus."

4. Braune, W. and Clasen, F. E.: Die Nebenhohlen der Menschlichen Nase in ihrer Bedeutung fur den Mechanismus des Riechens. Zeit. f. Anat. und Entwickelungsgeschichte Bd. II, 1876. S. 1.

5. Hartz, Henry J.: Remarks on the Physiology and Development of the Nose. Ann. Otol., Rhin. and Laryng., 18:709 (Dec.), 1909.

We know that forceful expiration produces a pattern different from that of a normal one.

Many reports are misleading because they are based upon conditions not encountered in the normal nose. Sometimes the pressures employed greatly exceed the natural ones, or as has been observed, models are used which do not duplicate conditions in the nose. More than one experimenter has simply employed a rectangular wooden box, through which air has been projected from end to end, the openings being opposite one another in the same axis! Unfortunately the findings in such experiments have been quoted and requoted until they have obtained some acceptance through repetition.

Paulsen[6] was the first to study the streaming of air in cadavers. He placed small squares of litmus paper in various locations upon the nasal mucosa, and passed ammonia fumes through the nasal chambers. By this means he established the inspiratory current as we now understand it, and found that even in forced inspiration only a relatively small part of the air reaches the olfactory region. Zwaardemaker, who had other ideas, questioned the manner in which the ammonia vapor was introduced, but Paulsen, according to his own reports, has apparently guarded carefully against adventitious effects. (Zwaardemaker himself used suction of 22 mm. of mercury, or 57 times the normal respiratory negative pressure!)

Zwaardemaker, Reuter and Cramer made a plaster model of a horse's nose, and passed soot from a smoking lamp through it, then they took the model apart and studied the deposits of soot, most of which they naturally found upon the front edges of the turbinates.

6. Paulsen, E.: Experimentelle untersuchungen über die Strömungen der Luft in der Nasenhöhle. Sitzungsbericht der K. Akademie der Wissenschaften. Section III. 1882.

Fig. 34. Motion picture sequence. Inspiratory air currents in the nasal fossa, demonstrated by mixing smoke with the inspired air. *Diagram superimposed upon the 3rd frame.*

Fig. 35 Motion picture sequence. Expiratory air currents in the nasal fossa, demonstrated in the same way. Diagram superimposed upon the 3rd frame.

Scheideler, working on the same principle, built models of the human nose with removable turbinates. He permitted streams of air saturated with corrosive substances to pass through these chambers, etching a record of their passage on the walls.

To this and to the last, one makes the same objection, namely, that it is an impingement pattern rather than one of air currents. Scheideler also confirmed the observation that the air patterns vary with the speed of the currents set up by the different pressures. A flow of 128 liters per minute produced a current directed toward the anterior end of the middle turbinate, being split there and passing above and below it to the choana. With a flow of less than 100 liters per minute, the same general direction was maintained but minor eddies were set up.

Scheideler's results are scarcely applicable to normal respiration, since most of them apply to an air flow of 128 liters per minute, whereas normal breathing progresses at the rate of about 27 liters per minute. (A man breathing 500 cc. 18 times a minute actually takes in 9 liters, but since inspiration is going on for only one-third of this time, the actual rate of flow is three times that, or 27 liters.)[7]

Hellmann[8] assuming that a stream of water would take the same pathway as an air current through the nasal chambers, cut a window in the nasal septum of a cadaver and immersed the head in a pan of water, studying the currents set up in the nose by means of a Politzer bag.

7. Scheideler, J.: The Air Currents in a Human Nose During Respiration. Ztschr. f Hals,- Nasen- u. Ohrenh., 44:228, 1938.
8 Hellmann, K.: Investigation of the Nose as an Airway. Ztschr. f. Hals-, Nasen- u. Ohrenh., 15:345 (Nov.), 1926.

Since friction is one of the chief factors influencing the pathways of fluids through tubes, observations predicating the similar behavior of such unlike media are open to criticism.

All experiments employing models for the study of air streaming are also suspect in that the model may deviate from nature's pattern in size, shape or texture sufficiently to vitiate the results. It is too often the case in models, especially in those which are increased in scale, that salient factors are omitted.

Franke[9] improved upon preceding experiments by using a human head, which he cut in two. Replacing the septum with a glass plate he passed tobacco smoke through the nose. He found the pathways much as Paulsen had described them, and as they are largely accepted today. He saw that expired air returned by the same path through which it entered, although he did not mention the large eddy, seen by the author, which finds its way into the middle meatus under the posterior third of the middle turbinate. For some reason his observation was not accepted by his contemporaries, as most of the textbooks appearing in the interval have described the expired air (when they mention it at all) as traversing the inferior meatus.

The author agrees with Franke on all points, his conclusions being based upon two groups of experiments.[10]

In the first small squares and strips of blue litmus paper were moistened with distilled water and placed in various locations in the nose. The subject was then allowed to inhale the

9. Franke, G.: Archiv. für Laryngologie und Rhinologie, 1:236, No. 2, 1893.
10. Proetz, A. W.: Some Intimate Studies of Nasal Function. Ann. Otol., Rhin. and Laryng., 41:125 (Mar.), 1932.

fumes of hydrochloric acid and the color changes of the litmus were observed.

The following precautions were observed to guard against errors due to diffusion: The subject was blindfolded and his attention was not directed to his respiration, in order to avoid any irregularities due to his attempts at co-operation. The bottle was held to his nose for only a fraction of a second in the middle of an inspiration, quickly removed while inspired air was still passing to clear the nasal passages of fumes, and the nose closed so that the breath was expired through the mouth. An interval of several respirations was allowed to elapse and the performance repeated. After about five such inspirations, the papers lying in or opposite the middle meatus and above that point were invariably red, those below it invariably blue. A long narrow strip of paper plastered against the septum midway back, and extending from top to bottom, came out particolored, the dividing line being approximately the lower edge of the middle turbinate.

Next acid fumes were gently pumped into the mouth during expiration so as to obtain expiratory effects. These gave much the same results with the litmus paper. The top turned red, the bottom remained blue—the difference being that the line of demarcation was somewhat lower and much less definite.

The second group of experiments which produced corresponding results and elicited a few details were as follows:

A head was sawed sagitally, exactly through the septum. This was clamped to a glass plate so that the nasal chamber could be observed (the glass occupying the position of the septum.) A rubber tube was fitted into the trachea, and wet cotton was packed around the entire preparation, making it

air tight but leaving the nostril accessible. Artificial respiratory currents were now set up through a tube in the trachea, pressures as near normal as possible, being established by means of manometers in the system. While these currents were passing, thin streams of smoke were introduced through cannulae into various portions of the nasal chamber, and their

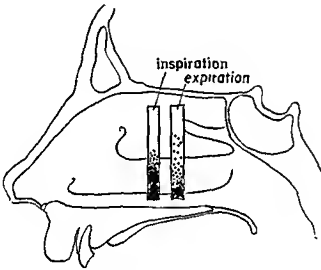

Fig. 36. Diagram of the author's test with litmus paper and hydrochloric acid fumes. Upper portions of the strips turned red Lower remained blue.

pathways studied. A steady inspiration or expiration could be maintained for an indefinite time at physiological pressures and the smoke currents carefully controlled and photographed. The normal fluctuations could also be reproduced.

For photographic purposes, it was found preferable sometimes to fill the nose first with smoke, and to observe the currents of clear air passing through it.

To estimate the importance of diffusion the head was cut again parallel to the first cut and one inch to one side. To this second surface another plate of glass was applied permitting inspection of the interiors of the sinuses. Small pieces of blotting paper moistened with hydrochloric acid were placed in the sinuses. By employing fumes of ammonia in the respiratory apparatus, the white clouds of ammonium chloride could be made to serve as indicators of the behavior of the air about the ostium. After twenty respiratory cycles, there was not enough of a chloride cloud to record with the camera. The same may be said of the smoke experiment. After half an hour's work with the air currents in the nose the interiors of the sinuses were rarely even hazy.

The inspiratory pathways observed corresponded to those of Lack and his contemporaries mentioned above.

On expiration conditions were reversed. Now, the air entered the choana uniformly throughout its extent, again passing upward. Influenced by the angle of the face of the sphenoid, it described much the same curve as it did on entering, except that the channel of greatest velocity was much broader. The relative sluggishness was caused by the retarding action of the restricted exit (nostril), and the current became accelerated in a narrow channel only as it prepared to leave the nose.

The inferior meatus conducted a definite stream of air only when excessive pressure was brought to bear, either by forced respiration or by restricting the nostril. There was a distinct triangular "air pocket" or area of calm on the floor of the nose posteriorly. According to these findings, the difficulty of blowing secretion from the nose while it is still in the middle or superior meatus, is due rather to the disseminated and dis-

persed nature of the outgoing blast than to the current flowing through the inferior meatus, as predicated by Lack.

Employing a head with thin and shrunken middle turbinates or one with an amputated middle turbinate did not materially alter either the inspiratory or expiratory currents.

Introducing obstacles of any description either on the septal or the lateral wall produced the most pronounced changes, in that the current was broken into eddies and whirls.

On inspiration, no current could be found to pass beneath the middle turbinate. On expiration, however, a distinct whirl could be seen to enter and to emerge from beneath it.

In watching the currents through the glass septum it is plainly seen that they follow the natural lines of the surfaces which they encounter. There are no special structures interrupting or deflecting the flow.

Fick[11] averred that the agger nasi forces the air forward under the bridge of the nose and thus, in an arch, to the olfactory region.

Others have failed to demonstrate this anterior air current. Zuckerkandl[12] represents the agger nasi as too inconstant to be considered of much importance as an air deflector.

The only striking characteristic which distinguishes the expiratory from the inspiratory path is the large central eddy. The significance of this has already been mentioned, namely, that only warm, humidified, expired air reaches the ostia.

11. Fick, A.: Anatomie und Physiologie der Sinnes organe. 1864.
12. Zuckerkandl, E.: Normale und pathologische Anatomie der Nasenhöhle und ihre Pneumatischen Anhange. Vienna, 1882, p. 30.

Currents passing through the ostia are extremely minute. They will be discussed in the following chapter, with the fluctuating pressures which produce them.

ADVENTITIOUS AIR JETS. The effect of restricting, deflecting or otherwise concentrating air streams, particularly during inspiration, upon any localized area of the mucosa may be very serious. Inspired air, playing in a jet upon a restricted area, rapidly evaporates the mucus, increasing its viscosity and preventing its movement by the cilia. Aside from this effect, which will be discussed in detail under the heading of ciliary activity, local drying and cooling may irritate the sensory nerves of the mucosa sufficiently to produce pain. Thus headache is produced more commonly by hyperventilation than by obstruction. If the process has not continued too long, headache resulting from overventilation can be controlled by plugging the nostrils (one or both, as required) with cotton.

To maintain the health of the nose it is necessary that the proper relationships between nostril, nasal fossa and choana be insured, since disproportions in the size and position of these structures result in the unequal distribution of air just mentioned and also in abnormally high or low peak pressures in the fossa and the sinuses, which in turn influence the vascular status of the tissues.

Fortunately the removal of the inferior turbinate has fallen into disuse, as the concentration of air upon the pharynx and the eustachian orifices resulting from the procedure often proved disastrous. The facility with which this turbinate swells and collapses and the pronounced influence which its fluctuations exert upon nasal air currents suggest that the large blood-spaces found in it have for their function the control of

respiratory capacity. Thus they constitute what is sometimes called the "nasal valve."

Chief offenders in the deviation of air currents are, first, spurs on the septum and abnormalities of the turbinates on the lateral wall; next, adhesions and occlusions, the aftermath of surgery or of severe ulcerative lesions; and last congenital atresias. While adenoids play an important part in the derangement of air pressures, they have little effect upon inspiratory air currents. Their deviation of expiratory currents is not so important because the expired air is warm and moist.

Impingement Effect of Constrictions. The effect of constrictions and other impediments to the air flow which cause it suddenly to change its direction is important in a manner which is seldom recognized. If an air stream carrying suspended particulate matter flows unimpeded and without change of direction through a straight tube of uniform diameter, very little of the suspended matter adheres to the walls of the tube, even though these be wet or the particulate matter adhesive. But if the tube is kinked, bent or constricted, small eddies are set up at the distal ends of these irregularities which cause the particles to impinge against the walls and to be deposited at these points.

For example, smoke may be blown through a short length of glass tubing for a considerable time without producing any discoloration in the tube, provided that the stream maintains a constant speed and the tube is straight. If constrictions occur in it a deposit of tar accumulates not within the constriction but just beyond it. If the tube is bent, the tar is deposited just beyond the bend. The importance of this phenomenon in nasal breathing lies in the fact that smoke, fumes, dust and

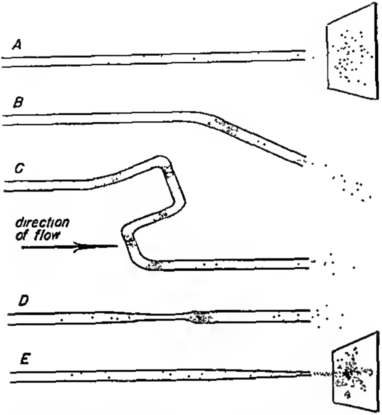

Fig. 37. Diagrams to demonstrate the deposit of suspended matter in air currents upon the walls of tubes through which it passes. This is by virtue of the "impingement effect" by which the particles are projected against the wall of the container wherever eddies are set up by constriction or change in direction of the airway. The deposit is always at the distal end of the impediment.

A Straight tube, current flows evenly, is projected gently against a flat surface. Deposit on walls of tube and plane surface negligible.

B Bent tube Deposit at distal end of bend.

C. Tube bent several times. In each case the deposit is at the distal end

D Tube constricted in its middle. Deposit at the distal end of the constriction.

E. Tube constricted at its end. Deposit forms upon the plane surface. If smoke is blown through such a tube onto a sheet of paper tar quickly piles up.

other irritative agents are concentrated upon the mucosa at points determined by constrictions, spurs and deviations. This accounts for the brown stains which appear about the nostrils of smokers who blow smoke through their noses. The tar is not deposited within the nasal fossae, but just distal to the points of greatest constriction, one centimeter within the nares. If one nasal chamber is wide and the other narrow, the brown stain will be seen only on the narrow side.

It will be seen that attempts to define the air currents by introducing dusts or lycopodium powder into the inspired air and mapping the deposits, or by passing corrosive fumes over models and studying the etching effects, as described, are likely to be misleading, as the currents under these conditions leave traces only where they impinge against the walls.

In 1932-33 Hilding described a series of very informative experiments demonstrating the end results of various surgical procedures upon the mucous membrane. They dealt in particular with the effects of nasal obstruction upon the morphology of the epithelium. He pointed out that there are areas in the anterior portion of the nose exposed to the impact of the inspired air in which there is little or no ciliary activity. He observed also, as others had done before him, that the more exposed areas of turbinated bones, spurs, ridges and polypi are relatively inactive compared to the depths of the meatuses and other more protected areas.

In a series of dogs and rabbits one nostril was surgically closed by suturing the tissues in layers, and the animals were killed after periods varying from six weeks to three months so that a comparison could be made between the membranes of the two fossae. Radical histological changes in the epithelium of both sides occurred.

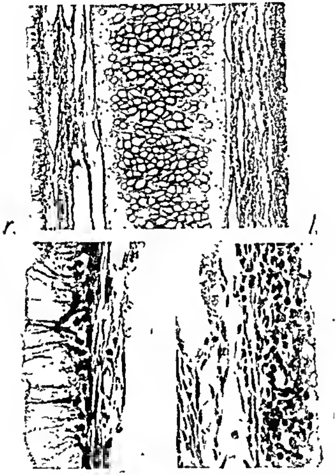

Fig 38 Photomicrograph. Section through the septum of a rabbit 128 days after surgical closure of the right nostril. X80. Below, sections of the epithelium, X450. (This and the following figure are from Hilding and are reproduced with the kind permission of the author and the Mayo Clinic.)

"In the rabbits, on the open side where the flow of air was doubled the cilia were lost and the epithelium took on a stratified form. On the closed side there was a great increase in goblet cells, that is cells filled with mucin and having no cilia. The changes in the dogs were somewhat different. . . . A section through the anterior portion of the septum of a dog 120 days after closure of the right nostril [shows] the lining of the open side has become very much like a thin squamous type of epithelium. The subepithelium has increased in thickness and the number of lymphocytes it contains has been definitely increased."[13] Unlike the rabbit there was no increase in mucin-containing cells on the closed side in the dog, instead these were tall and well-ciliated.

In this connection Hilding found that when, in the course of his experiments, the frontal sinuses of dogs were exposed to open air the epithelium became red, thickened and velvety and sometimes crusted where they were most exposed. These changes were much less pronounced in the deeper regions and in those sheltered by a bony overhang. The same was true of ciliary motion which was absent in the exposed areas and present in the protected ones.

Degenerative changes occur in the olfactory mucosa as well, at least in experimental rabbits. The atrophy is confined to the first neuron from the olfactory mucosa to the bulb. If the

13. Hilding, Anderson: Experimental Surgery of the Nose and Sinuses. I. Changes in the Morphology of the Epithelium Following Variations in Ventilation. Arch. Otolaryng., 16.9 (July), 1932. II. Gross Results Following Removal of the Intersinus Septum and of Strips of Mucous Membrane from the Frontal Sinus of the Dog. Ibid., 17.321 (Mar.), 1933. III. Results Following Partial and Complete Removal of the *Lining Mucous Membrane from the Frontal Sinus of the Dog.* Ibid., 17.760 (June), 1933.

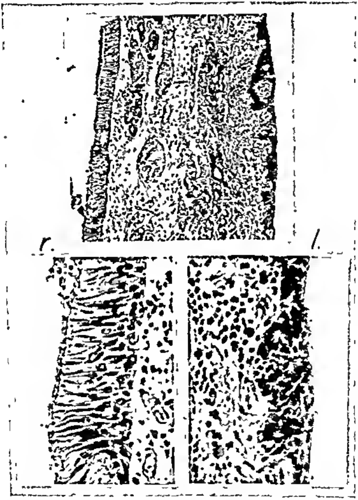

Fig. 39. Photomicrograph. Section through the septum of a dog 128 days after surgical closure of the right nostril. X80. Below, sections of the epithelium. X450.

obstruction has persisted for any length of time, olfactory perception does not return after its removal.[14]

In several patients, however, in whom breathing had been in abeyance from three to six years due to palatal adhesions or to cicatrical obstruction of the nostrils, the ciliated epithelium of the mucosa was found to be perfectly normal.[15]

The measurement of nasal patency for clinical purposes has been often attempted. The simplest device is the metal mirror of Glatzel upon which the patient is allowed to breathe. If one regards only the size and shape of the moisture deposits, he will have little more than a relative idea of the size and shape of the nostrils, since these determine the pattern.

Additional information may be gained by recording the evaporation time for each side,[16] but even this provides only a rough estimate if the areas of the two patterns differ widely, since a given quantity of moisture will evaporate faster from a larger area than from a smaller one.

The test often reveals that a nasal fossa, which to the examiner's eye appears obstructed, actually delivers as much air as its fellow, the apparent obstruction being due to distorted contours without loss of section area.

AIR CURRENTS IN THE SINUSES. Air fluctuations through the ostia are rarely of such force or magnitude as to carry foreign matter into the sinuses but they are at least sufficient

14. Frühwald, V.: Effect of Closure of a Nostril on the Olfactory Mucous Membrane and on the Bulbus and Tractus Olfactorius. Arch. f. Ohren. Nasen-u. Kehlkopf., 139-153 (Mar. 20), 1935.

15. Fetissow, A. G.: The Effect of the Absence of Nasal Respiration on the Structure of the Nasal Mucous Membrane. Acta Otolaryng., 21:2-3, 1934

16. Lieb, C. C., and Mulinos, M. G.: Mirror of Glatzel as a Measure of Nasal Patency. *Arch. Otolaryng.*, 30:334, 1939.

to agitate small masses of mucus which may momentarily cover the ostia, in that manner assisting in keeping the openings free.

As has been stated, the impression that an accessory ostium permits through and through air flow during respiration is fallacious, as pressures in the nose act upon the two openings equally and simultaneously thus maintaining equilibrium between them.

Air currents in the sinuses themselves are negligible.

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CHAPTER VII

AIR PRESSURES

THE THORACIC BELLOWS—NOSTRIL AND CHOANA—RECIPROCAL EFFECTS BETWEEN NOSE AND CHEST—BRAUNE AND CLASEN — EXPERIMENT — SINUS PRESSURES AND BOYLE'S LAW—MINUTE AIR EXCHANGE.

THE THORACIC BELLOWS. The respiratory excursions of the thoracic bellows, which we call breathing, naturally set up alternating positive and negative pressures in the nasal chambers, which are concomitant in time, phase, duration and extent with the thoracic pressures. The degree to which these pressures must be established in the pharynx in order to maintain the nasal air flow depends upon the resistance encountered in the nasal passages. This, in the normal nose, is determined largely by the section of the nares.

The relative sizes of nostril and choana determine the positive and negative pressures in the nasal fossa. Minor variations in the section of one or the other and in the section of the nasal chambers result in pressure changes which appear quite disproportionate on clinical examination.

The anterior nares, which by virtue of their constriction are chiefly responsible for the direction of the air currents, also influence the nasal pressures for much the same reason.

The force and the time expended in passing the required amount of air to the lungs depend upon the section of this narrowest point. As a rule less resistance is encountered than

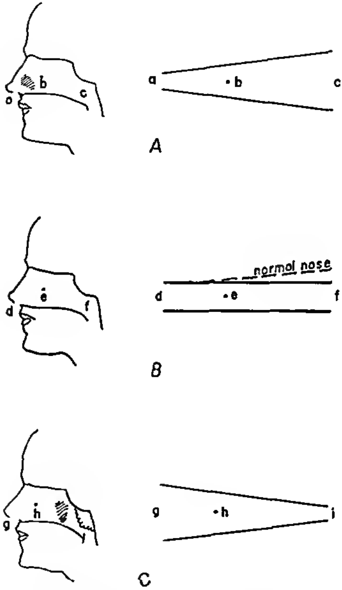

Fig 40. Diagrams to demonstrate the effects of the nasal proportions upon the air pressures at the ostia.

A. In this case there is a narrowing of the anterior naris a, or any *other constriction in the anterior part of the nasal fossa, while* the choana, c, is of normal or greater than normal section. The thoracic bellows forces against the constriction, a, in both inspiration and expiration, and accentuates negative and positive pressures at the ostium, b

B. As the two orifices approach one another in size ths pressures become normal. In the normal human nose the naris is slightly smaller than the choana, and the conditions lie somewhere between A and B.

C. When the naris is normal or large, and there is some posterior obstruction, the thoracic bellows forces against the constriction, i, nasal pressures are quickly equalized through g, and only slight fluctuations occur at the ostium, h.

is generally supposed. Pressures set up in the pharynx and transmitted to the nose and the sinuses, are rapidly equalized.

Respiratory pressures at the glottis are generally conceded to fluctuate from +6 mm. to —8 mm. (water) during nasal breathing with the mouth closed.[1,2]

NOSTRIL AND CHOANA. As the pharyngeal pressure rises and falls above and below the atmospheric pressure at the nostril, there must exist, at the various ostia, pressures somewhere between the two. The pressure at any given ostium depends first upon its position relative to the nostril and the choana, and second upon the relative sizes of these two orifices. If the nostril is large and offers little resistance, then only small pressures are built up. The same is true if there is a pharyngeal obstruction such as an adenoid. If the nostril is comparatively small or obstructed and the choana of normal size, then the pressure fluctuations in the nose are correspondingly large.

When as a result of strenuous exertion there is a strong involuntary stimulation of the respiratory center, the nasal alae take part in the response of the respiratory musculature and dilate.[3]

Van Dishoeck believes that during forced breathing the negative pressure of the nose is not decreased as might be expected,

1. Mink, P. J.: Le nez comme voie respiratoire. Presse Oto-Laryng. Belge 2, 421 and 481. 1903.
2. Uddstromer, Martin: Nasal Respiration. A Critical Survey of Some Current Physiological and Clinical Aspects on the Respiratory Mechanism with a Description of a New Method of Diagnosis. Acta Oto-Laryngologica. Supplement 42, 1940.
3. Van Dishoeck, H. A. E.: Electrogram of the Alar Muscles in Dyspnea and Hyperventilation. Acta Oto-Laryngologica, 26:1, 1938.

owing to the distention and dilatation of the nares at such times.[4]

Conversely Kerekes[5] deduces, from experiments upon man and animals, that nasal air currents in the nose and sinuses reflexly influence the mechanism of respiration, and are part of the regulatory system of automatic breathing.

Since no two faces are identical and likewise no two noses, it follows that the "normal" intranasal pressures indicated by various authors differ somewhat. A study of many reports from many individuals, however, fixes these pressures at approximately +6 mm. to —6 mm. (water). This varies from minute to minute in the individual with the state of the nasal tissues. Intranasal pressure may be reduced as much as fifty per cent by cocaine applications.[6, 7]

Braune and Clasen. In the matter of air pressures, all investigators hark back to the works of Braune and Clasen.[8] This much quoted pair were the first to institute comprehensive and accurate measurements of respiratory air pressures, although they in turn quote Donders as having somewhat preceded them in one or two observations.

These three are agreed that the strongest inspiratory effort against closed mouth and nostrils reaches a maximum negative

4. Van Dishoeck, H. A. E.: Electrogram of the Alar Muscles and Resistance Curves of the Nose. Acta Oto-Laryngologica, 25:285 (Fasc. 4), 1937.

5. Kerekes, G.: Nasennebenhohlen und Atemmechanismus. Acta Oto-laryng., 21 438, 1935.

6. Hartz, H. J.: Remarks on the Physiology and Development of the Nose and Accessory Sinuses and Nasal Reflexes with Special Reference to the Function and Importance of the Turbinated Bodies. Ann. Otol., Rhin. and Laryng., 18:709 (Dec.), 1909.

7. Mink, P. J.: Physiologie der oberen Luftwege, Leipzig, 1920.

8. Braune, W. and Clasen, F. E.: Die Nebenhöhlen der menschlichen Nase in ihrer Bedeutung für den Mechanismus des Riechens. Zeitsch. für Anatomie und Entw., 2:1, 1876.

pressure of —57 mm. of mercury, and the strongest expiratory effort a maximum positive pressure of +87 mm. of mercury.

Many of their observations were conducted with a manometer firmly sealed into and thus closing one nostril. Since this does not reproduce the condition of natural breathing and decreases the section of the port by one-half, we will not dwell upon the figures thus obtained.

The classical experiment of these two investigators, however, was conducted in the following manner. A cadaver was employed which had been sawed across at the level of the trachea. A rubber tube was sealed into the open trachea, which was held in the mouth of "a healthy, strong man who inhaled and exhaled lustily into it." Water manometers were now applied to the nasal chambers of the cadaver and readings made. With ordinary breathing, that is with an inspiration lasting roughly 1.5 seconds, the manometer connected with the maxillary sinus recorded negative pressure approximating 8 mm., while that in the nose approximated 10 mm., which was, however, rapidly equalized.

During a forcible inspiration, a negative pressure of 200 mm. (water) was obtained in the nose, but only —190 in the maxillary sinus.

They concluded that the pressures in the nose were dependent upon the depth and rapidity of inspiration. That rapid inspiration and expiration have the effect of building up excessive pressures against the restriction at the nostril, and must determine the nasal pressures, is clear. That the length of time during which the flow is maintained, in other words the depth of the respiration, could have any effect on it is not

based on sound physical grounds, nor is this confirmed by the evidence of others.

EXPERIMENT. The author has, for his own purposes repeated these experiments with minor variations. For the guidance of the student, who may wish to observe the phenomena for himself the following description[9] is appended:

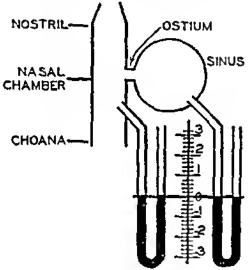

Fig. 41. Scheme of manometers in the nasal chamber and the sinus for the determination of air pressures.

Twin water manometers were prepared and connected with two similar antrum puncture needles. One of the needles was introduced into the antrum via the inferior meatus. The other was held with its tip midway back in the nasal fossa.

(It is essential to accuracy that no water from the sterilizer be allowed to remain in the tubing or the needles!)

9. Proetz, Arthur W: Some Intimate Studies of Nasal Function: Their Bearing on Diagnosis and Treatment. Ann. of Otol., Rhin. and Laryng., *41*.125-140 (Mar.), 1932.

The figures of Braune and Clasen were verified: The antrum manometer registered, in relatively unobstructed noses, from 4 to 7 mm. of water pressure plus and minus, averaging a total fluctuation of 10 mm. As was to be expected, the pressures in the nasal chamber corresponded closely to those in the sinus so long as the ostium remained open.

A glass-and-rubber model can be easily constructed by means of which the effects of obstructing the ostium, the nostril or the choana may be observed. With this model it may be shown that:

1. So long as the ostium remains at all patent, the pressure changes in the sinus are identical with the pressure changes in the nose.

2. As the ostium narrows, a progressively increasing time-lag occurs in the fluctuations of pressure within the sinuses, so that it requires a short but appreciable time for the equalization of pressure on the two sides of the ostium.

3. Regardless of this time-lag, the peak pressures are not affected until the ostium finally closes altogether, when they cease completely.

4. On restriction of the nostril alone, the peak pressures, both plus and minus for a given respiration, are increased in both the nasal fossa and the sinus.

5. On restriction of the choana alone, the peak pressures, both the plus and minus for the same respiration, are reduced in both the nasal fossa and the sinus.

6. On restricting both nostril and choana, the pressures vary between wide limits in direct proportion to the relative restrictions.

Some practical clinical applications of these phenomena are the following:

Variations in the speed or the promptness of sinus fluctuations represent changes at the ostium; variations in pressure peaks represent changes in the nasal chamber.

If there is fluctuation in the sinuses, the ostium is open.

If there is no fluctuation, the ostium is shut.

If there is fluctuation only on forced respiration and the fluid level fails to return to normal, the ostium is swollen but still penetrable.

If the fluctuation is slow to reach the peak, the ostium is narrowed.

If the excursion of fluid on normal breathing is reduced (diminished peak pressure), there is nasal obstruction behind the ostium.

If the excursion on normal breathing is exaggerated (increased peak pressure), there is nasal obstruction anterior to the ostium.

If the membrane is swollen and the ostium is obstructed, the pulse-beat may be observed in the manometer, and there is no fluctuation.

The manometer for clinical use is simply a piece of glass tubing bent U-shaped and half filled with water. It need not be calibrated. The behavior of the fluid is definite and characteristic. The tube should be attached to the needle before puncturing or, if attached afterward, the connection

should be by means of a bayonet joint and not by slipping the rubber hose over a glass adapter, as this creates a positive pressure in the system if the ostium happens to be closed.

Rockwell Coffin[10] reported a positive antrum pressure averaging 1.17 cm. in apparently normal noses, with the respiration at rest.

This has not been found by others and it is difficult to explain on theoretical grounds. With breathing at rest and the ostium open, nose and sinus must both be at atmospheric pressure. It is conceivable that gas exchanges between the confined air and the mucosa might gradually create a small plus or minus pressure, provided the ostium were tightly closed.

A sort of Beaumont-St. Martin observation was conducted by Carcò[11] upon a man with a permanent external opening in his frontal sinus resulting from an injury. A manometer was adjusted to the opening in the forehead by which variations of the air pressure within could be studied.

SINUS CONTENTS AND BOYLE'S LAW. Since these pressure changes in the nose are solely responsible for whatever air currents may traverse the ostia, they have an important bearing on the physiology of the sinuses. Having measured them, one may easily calculate the volume of air passing to and from a given sinus during a respiratory cycle.

One atmosphere of pressure, regarded at sea level as about 760 mm. of mercury is equivalent to a column of 10,260 mm.

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10 Coffin, Rockwell A.: Experiments with Atmospheric Pressure in the Maxillary Sinus. Trans. Am. Laryng. Assoc., 1922, pp. 291-297.

11. Carco, P.: Sulla Partecipazione seno frontale dell'uomo alle modificazioni della meccanica respiratoria. Fisiole. e med., 6:1035 (Dec. 20), 1935.

of water. A fluctuation of 10 mm. (average respiratory cycle) then represents a variation of 1/1026 of an atmosphere of pressure. According to Boyle's law the volume of a gas varies inversely as the pressure, the temperature remaining constant. This means that the air contained in a sinus varies only 1/1026 in its volume with each respiratory cycle.

MINUTE AIR EXCHANGE. Thus in a maxillary sinus of, say, 15 cc. capacity the air exchange is a little less than 15 cu. mm. In an ethmoid cell of 1 cc. the exchange at the same time is less than a single cubic millimeter!

Even if, by some means, this amount of fresh air could be taken into the sinus and an equal amount of stale air extruded with each respiration, it would require 1026 respirations (almost an hour) to completely change the air in the sinus.

But of course so effective a means of exchange is wanting. Instead, with each respiratory cycle this minute amount of air is introduced and immediately withdrawn. So tiny a fluctuation through the ostium is not of a nature nor of an extent capable of setting up any currents in the sinus, wherefore the cavity must depend for its air exchange upon very gradual diffusion.

Putting it practically, it requires hours for a complete exchange of air to take place.

Under certain pathological conditions negative pressures may be maintained in the sinuses. Polyps in the neighborhood of the ostia may act as ball valves closing the openings after the negative pressure cycle, thus maintaining these pressures for a time.[12]

Theories that air pressures in the nose and in the growing sinuses have a determining effect upon the development of the latter have already been referred to.

12 O'Malley, J. F.: Ventilation of the Nose and Accessory Sinuses: Oscillograph Method of Investigation. J. Laryng. and Otol., 50:389 (June), 1935.

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CHAPTER VIII

RESPIRATION AND AIR EXCHANGE

THE NATURE OF AIR EXCHANGE—"VACUUM HEADACHE"—CARBON DIOXIDE—DIFFUSION—POSITIVE AND NEGATIVE PRESSURES.

Among the many vague theories advanced to explain the function of the sinuses there appear invariably the short references "adjunct to respiration", and "moistening the inspired air", but there is never any attempt to explain just what is meant by adjunct to respiration, nor how the moistening of the inspired air is supposed to take place. In view of what has just been shown regarding the minute interchange of gases between the nose and the sinuses, there is scant foundation for such hypotheses.

THE NATURE OF AIR EXCHANGE. If an air exchange exists between the mucosa and the air contained in the sinus, a careful distinction should be made between exchange of gases and absorption of gases, because upon this distinction depends the phenomenon on which so-called vacuum headaches have been not too satisfactorily explained.

"VACUUM HEADACHE". The term "vacuum headache" has been frequently employed and the condition generally accepted but very little consideration has been given to the possible source of such a vacuum. Sluder, who first gave prominence to the idea, simply states his belief that "the tenderness of the wall of the frontal sinus arises secondarily to the closure of its outlet, and that a similar condition obtains

here to that produced in the middle ear by sudden closure of the eustachian tube. Many years ago this was recognized as a condition in which the oxygen of the enclosed air was absorbed and a negative pressure, a partial vacuum, established within the cavity."[1]

He makes no reference to the manner in which the oxygen is absorbed, but presumably he conceives the absorption as taking place by the epithelium, or through it, by the blood.

According to Hartz a reduction of pressure occurs in the sinuses after obstruction due to a "rarefaction of gases in the space . . . as a result of the absorption of oxygen and its replacement by a smaller volume of carbon dioxide."[2]

Unfortunately no definite information is available concerning gas distribution or differential absorption in this region. On the basis of gas exchange in other tissues the situation here would probably be one in which some decrease in oxygen occurred in the sinus together with a slight relative increase in carbon dioxide. Thus a slight increase in pressure may conceivably result but one can think of no condition under which a vacuum might be created.

CARBON DIOXIDE. Hellmann sealed the nasopharynx by pressing gauze packs against the soft palate. Measured amounts of air were then passed through the nasal chambers and bubbled through a solution of barium hydroxide. He stated that .00039 grams of carbon dioxide per minute were given off by the nose. He computed from this that the amount

1. Sluder, Greenfield: Nasal Neurology, Headaches and Eye Disorders. C. V. Mosby Co., St. Louis, 1927, p. 35.

2. Hartz, H. J.: Remarks on the Physiology and Development of the Nose and Accessory Sinuses, etc. Ann. Otol., Rhin. and Laryng., 18:709 (Dec.), 1909.

secreted in 24 hours is .004 gr. per sq. cm. or seven times the amount per sq. cm. given off from the lung.

Assuming these observations to be accurate, they can be of importance only in respect to carbon dioxide concentration, as the actual amount is insignificant in view of the small area concerned and the slow exchanges through the ostium.

Opinions differ as to the area of the nasal mucosa. Leuvens puts it at 200 sq. cm., Hellmann[3] at 67. The latter computes that the surface of the alveoli is some 6000 times this area.

In air-breathing animals the inspired air is all but brought in contact with the circulating blood in the lung, being separated from it by a membrane only a single cell in thickness.

It is problematical whether the much thicker, differentiated epithelium of the nasal chambers, itself covered by a jungle of mucus and rapidly moving cilia, is acting similarly. If diffusion is an element in the distribution of gases at the surface of the membrane then the small size of the ostium in turn becomes an important element, since it permits only a minute amount of air exchange between sinus and nasal fossa.

Diffusion. The tension of a gas in any mixture of gases is proportional to its relative concentration. If a mixture of gases is placed in contact with a watery medium and diffusion is allowed to continue until equilibrium is reached the tension of the various gases in the two phases will be equal. If the ostium were closed therefore an equilibrium would sooner or later be reached which, as stated above, would result rather in a slightly increased pressure than a partial vacuum.

3. Hellmann, Karl: Über den Gaswechsel der Nase. Zeitschr. f. Laryng Rinolog u Otolog., 15:181, 1926-27.

Even if this were not so, and through some special selectivity the oxygen were removed from the confined air by the sinus epithelium, it is difficult to conceive of a vacuum enduring in a sinus for longer than a few minutes. In this location the connective tissue stroma of the tunica propria is extremely distensible so that a vacuum would rapidly produce a hyperemia and, almost as rapidly, an edema.

Such changes readily occur under the influence of irritative, infectious and allergic stimuli, and it is remarkable that these sudden mucosal distentions and recessions taking place in the presence of an obstructed ostium have never been credited with the variations in air pressure.

POSITIVE AND NEGATIVE PRESSURES. These pressures are familiar to everyone who has suffered the discomforts of an acute sinusitis. In the quietude of the night the hiss of small volumes of escaping air can be heard as well as felt by the patient. That the air, under these circumstances, is ordinarily passing out of the sinus and not into it can be demonstrated. If a progressive swelling of the sinus lining has lightly closed the ostium, then any further swelling must necessarily produce a positive pressure, which may continue to a sufficient degree to cause pain.

By the same mechanism it is not without the bounds of possibility that a swelling membrane might force part of the enclosed air from the sinus cavity, and that later, still in the presence of a blocked ostium, a partial vacuum might occur when the membrane became depleted through its vascular channels.

Let us examine for a moment the possible effects of the minute air exchanges between the nose and sinuses under

physiological conditions. Certainly they form no significant component of the inspiratory air stream and can therefore have little to do with warming or moistening it. The pressure changes taking place simultaneously with respiratory air flows, and ceasing with them, can likewise have no influence on the sense of smell by retaining or otherwise affecting inspired particles.

Thus it becomes fairly apparent that the air pressures and exchanges in the sinuses are purely incidental to their positions, relative to the air flow, and require no special physiological interpretation.

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CHAPTER IX

HUMIDIFICATION

PURPOSE OF HUMIDIFICATION—ADAPTABILITY—EFFECTIVENESS — ABSOLUTE AND RELATIVE HUMIDITY—HUMIDITY IN THE RESPIRATORY TRACT—GLANDS—BLOOD SUPPLY — EFFECTS OF DRYING — LOCALIZED DRYING—AIR-CONDITIONING.

Humidification and warming of the inspired air are accomplished with amazing efficiency by the nose.

It was understood as early as 1886 that the air reaches the larynx at temperatures over 30° and practically saturated.[1]

PURPOSE OF HUMIDIFICATION. The adequate humidification of the inspired air is an extremely important adjunct to normal respiration. The alveolar epithelium a delicate structure, whose walls are but a single cell in thickness, must be protected from injury and drying. In fact the exchange of gases itself requires a moist surface.

The protection of the respiratory epithelium against irritative and obstructive foreign material depends upon the ciliated linings of the pulmonary airways and the upper respiratory tract, which even a transient drying will so incapacitate that the cilia will have to be renewed before function can be resumed. Therefore it is important not only that the surface shall be moist, but that it shall be constantly so.

1. Aschenbrandt: Die Bedeutung der Nase für die Atmung. Würzberg. 1886.

The moisture must be supplied in the required quantities and its flow regulated, as either an over- or an under-abundance of it will hamper proper ciliary drainage.

The pharynx which is the only zone of the respiratory tract without cilia cleanses itself by other means. Here the constrictor muscles of the pharynx and the palate maintain a continual wiping action which disposes of foreign matter by way of the esophagus.

Since ciliary streaming from the lower respiratory tract is upward and that from the nasal chambers is backward, it follows that all deposits from the entire respiratory system accumulate in the pharynx whence they are removed by swallowing or expectoration. Aside from the pharynx the air passages are rigid and no wiping action is possible, therefore the cleansing of these parts devolves entirely upon the cilia.

ADAPTABILITY. Just as the secretion of saliva is modified by the requirements of mastication and degutition, so the glands of the nasal mucosa respond to environmental influences. The extremes of heat and humidity encountered under modern living conditions make great demands upon the nasal mucosa. In cold weather the absolute humidity is much reduced. When this dry air is inducted into our living quarters and heated, the relative humidity may fall as low as five to ten per cent and remain there throughout the winter season. Thus is strained to its capacity the nasal mucosa whose task it is to humidify this air to something like saturation before it reaches the lung.

EFFECTIVENESS. A man at his ordinary occupations breathes in the neighborhood of 500 cubic feet of air a day. The fact that the relatively small nasal chambers are capable of completely humidifying it during its passage, points

not only to an extremely effective mechanism but also to the necessity of keeping this mechanism functioning in its entirety.

To be sure, the nasal surfaces are not so severely taxed as they would be were the air passing through continuously in one direction. Surfaces which have been dried during inspiration are moistened again to some extent by the expiratory currents. Condensation takes place on the surfaces chilled by evaporation.

The possible physiological and pathological effects of the constant alternation of temperatures in the nose have been very incompletely studied.

ABSOLUTE AND RELATIVE HUMIDITY. By absolute humidity of air is meant the percentage by weight of water vapor in its composition.

By relative humidity is meant the vapor content expressed as a fraction or percentage of the concentration required to saturate the air at a given temperature.

This complete (100%) saturation is called the "dew point". If the temperature is raised without adding moisture the absolute humidity remains the same but the relative humidity is reduced because the air can now take up additional water and is less than saturated.

The relative humidity is measured by means of a psychrometer. This ordinarily consists of a pair of thermometers, the bulb of one of which is kept wet by means of a wick. The speed of evaporation from the wet bulb is determined by the humidity of the air, and the heat loss is indicated by the thermometer. Thus the relative humidity may be computed from the readings of the two thermometers.

Although the saturation of 500 cu. ft. of air at body temperature consumes less than .7 liter of water, nevertheless the nose has been shown to secrete in the neighborhood of a liter in 24 hours, the balance being applied to the cleansing process and ultimately swallowed.

Complete saturation of the inspired air by the nasal mucosa is not possible, being variously estimated at 75% to 95% relative humidity.

Seeley[2] makes the point that saturation of air takes place only over pure water. He contends that over any solution, which includes the nasal mucus, saturation cannot occur due to the decreased water vapor pressure of the solution. He adds that in the mechanism of breathing cold air there is a recovery of heat from the expired air as well as from the condensed water vapor. He has measured the response of the warm, moist surfaces to different relative humidities, and finds that not the least important effect of a sudden change of air conditions may be the equally sudden change in the evaporation rate. To compensate for this the nose is often at a loss. "If moisture" he states, "is evaporated from the mucosa at an accelerated rate due to change of temperature and/or relative humidity, it follows that the characteristics of that mucosa must change in viscosity, surface tension, osmotic pressure, etc., unless a greater supply of water is added to this mucus or else a greater quantity of mucus itself is supplied. Unless compensation is instantaneous it must be conceded that at least the physical character of the mucus is changed by its altered rate of water loss. This may be quite important."

2. Seeley, Lauren E.: Study of Changes in the Temperature and Water Vapor Content of Respired Air in the Nasal Cavity. Heating, Piping and Air-Conditioning, No. 51, p. 377 (June), 1940.

HUMIDITY IN THE RESPIRATORY TRACT. Perwitzschky fixes the relative humidity of the inspired air as it leaves the nose at 79%. He credits the trachea with adding another 15% before it reaches the alveoli. It is the observation of this author[3] as well as some others, that in mouth-breathing the humidity of the air as it reaches the larynx is only slightly less than in nasal breathing.

Under experimental conditions it may be true that the mouth can humidify inspired air to the same degree as the nose, but surely its effectiveness diminishes with a few breaths. One has only to examine a mouth-breather in the morning to convince himself of the superiority of the nose over the mouth as a humidifier.

In respiration through a tracheal cannula, inspired air is not warmed to body temperature until it reaches the smallest bronchi, and the humidity in the upper bronchi in this case is only 62%.

There is little difference in the degree of saturation of inspired air at the various levels of the respiratory tract, whether outer air humidity be 24% or 40%. Increased secretory activity of the nasal glands does not normally increase the humidity of the inspired air, but merely permits the same degree of humidity for a longer time with the continued movement of air. Expired air is only two to three degrees cooler than alveolar air.

The quantity of water required to saturate the air inspired in the course of twenty-four hours varies with the temperature

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3. Perwitzschky, R.: Temperature and Moisture of Air in Air Passages Under Normal Depth of Breathing in Resting Man. Arch. f. O.N.u. Kehlkopf., 117:1-36 (Nov.), 1927. Biol. Abstracts, 3:1-36, No. 4-6 (Apr.-June), 1928, Entry 6334.

and the state of saturation of the atmospheric air. The daily 15,000 liters of dry air at 37° C. requires some 680 cc. for saturation.

GLANDS. The mucosa makes every attempt to maintain sufficient moisture on its surface, even under adverse conditions. In the healthy state mucus is supplied partly by goblet cells, but in the main by glands which are distributed over the mucosa in direct relationship to the requirements. The rich vascular supply insures abundant nourishment and moisture to these structures.

Under adverse circumstances in which the glandular mucus fails or falls short there occurs an increase in goblet cells in an attempt, often only partly successful, to compensate for the loss.

In the nasal fossa glands are very numerous. They may be anything from mere pits in the epithelium dipping into the tunica, to the more complicated tubo-alveolar type reaching the surface through a proper duct. The duct opens onto the free surface of the membrane, and the orifice is lined with cilia which help to convey the mucus to the surface. The glands of this type are apt to be mixed, the ovoid terminal alveoli consisting of mucus cells, interspersed between groups of serous cells.

The mucosa of the sinuses resembles that of the nose except that it is thinner and contains fewer glands. The distribution of these glands is directly proportional to the physiological demand for the mucus which they secrete: They are relatively numerous about the ostium and thin out progressively to the more remote regions, where there are only enough to form the mucous film, or "blanket".

Fig 42. Photomicrograph, respiratory nasal mucosa. On the left the duct is seen to be lined with ciliated epithelium. The cilia in this position assist in extruding the mucus onto the surface of the membrane.

Blood Supply. The blood supply of the tunica propria is abundant, most particularly in the membrane overlying the turbinated bones. The deeper arteries send branches through the tunica to form a subepithelial network of capillaries. From this network the blood progresses to a superficial venous plexus, thence to a deep venous plexus. This system of blood cavities, the plexus cavernosi concharum, is erectile and is distributed chiefly over the inferior concha and along the free margins of the middle concha. It is especially prominent at their posterior tips. The membrane of the septum opposite these regions is also moderately erectile.

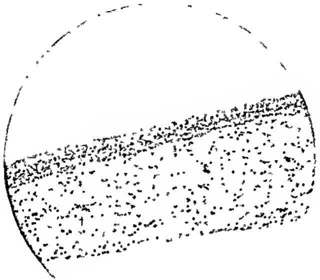

Fig. 43. Photomicrograph, mucosa from the ethmoidal sinus. The membrane is thin and almost devoid of glands

Engorgement and depletion of these tissues are under reflex nervous control. While regulating humidification and heat they undoubtedly function also as an intake valve for the upper respiratory system.

Effects of Drying. The failure of nasal humidification affects the health and comfort of the individual in proportion to its extent and distribution. This failure may be due either to a general lack of glandular function or to local conditions, chiefly mechanical, which may at first only deflect the air stream from the moistening surface but which later, by so doing, bring about a metaplasia and a reduction in secretory elements.

Probably the best example of extreme drying is the condition encountered in atrophic rhinitis. Although even here a certain amount of moisture is given off by the mucosa, it is quite inadequate for the requirements of inspired air with the result that what mucus there is, is dried and crusted. These crusts then present an entirely dry surface to the air stream.

The general results of such a drying are widespread. The patient, conscious of the inspissated material in his nose, is by the very nature of the situation, unable to rid himself of it. Not only is it extremely adhesive, but the walls of the nasal chambers through atrophy have so receded from one another that expulsive currents are practically impossible.

The pharynx in turn becomes dry and the patient attempts to moisten it by repeatedly swallowing and clearing his throat, which is only partly successful owing to the limited effectiveness of the wiping action of the palate[4] and the rapid evaporation of the saliva.

The condition known as pharyngitis sicca ensues in which the pharyngeal membrane is red, dry and glassy. Similar effects are produced in the larynx (laryngitis sicea), and either of them may be present without the other.

The conversation of persons suffering from these conditions is constantly interrupted by their efforts to moisten their throats, and their voices are apt to be husky.

Lesser symptoms of lack of humidification are frequently seen, and although the disturbances in these cases have not yet reached the status just described the differences lie in degree rather than in kind.

4. Sluder, Greenfield: Die Wechselbeziehungen zwischen Aktion des Pharynx und des weichen Gaumen und ihre Bedeutung für die Diagnostik der Verhältnisse im Nasenrachenraum. Archiv. für Laryng. und Rhin., 1915.

Fig. 44. Photomicrograph. Experimental localized drying of the mucosa, lower center. In this area the mucus is thick and ciliary activity has ceased.

Localized Drying. Localized drying, brought about by asymmetries, distortions and partial constrictions, eventuates in a variety of symptoms depending upon the location in which the drying occurs. This may be anywhere in the nose but the more troublesome locations are the face of the sphenoid, the epipharynx, the region of the nasal ganglion and the orifice of the eustachian tube.

The alteration of the membrane in such a locale is comparable to that described by Hilding following the experiments cited in which he closed the nostrils of dogs and rabbits surgically. (See pp. 132-4.)

The clinical result in any event is an early incapacity and a later destruction of cilia where these exist, and presently a piling up and drying of nasal mucus. Cleansing ceases, irritative matter is not removed, and local inflammation, discomfort and pain follow.

In this gelatinous state the mucus constitutes an excellent culture medium, bacteria flourish and penetrate the mucosa.

If the locus happens to be the epipharynx, discomfort, drying and burning are the chief symptoms. If it is the face of the sphenoid, the region of the spheno-palatine ganglion, or any other particularly sensitive area in the nasal vault, headaches and retro-orbital pains ensue. If it is the lip of the eustachian tube, the symptoms are discomfort and a sensation of obstruction, and sometimes impairment of hearing.

A dry nose is at the root of most of the fall epidemics of coughs and colds. Coincidental with the institution of furnace heat at this time, patients complain of smarting and burning in the pharynx, and the familiar infections quickly make their appearance. These are often attributed by the victim to the inclement weather which necessitates the furnace heat, but the characteristic dry spots are incriminating evidence against the low humidity.

Furthermore, these irritations usually persist until proper steps are taken to humidify the air in the patient's apartments, and especially in his sleeping quarters. This is usually the only remedy necessary.

Medical means of overcoming nasal dryness will be discussed in the chapter on treatment.

AIR-CONDITIONING. A few observations regarding air-conditioning may not be amiss in this place. Numerous systems have been placed on the market; some of them are designed to meet physiological needs, many are not. The rhinologist can be of much help to his patient if he will familiarize himself with the requirements of the nose, and recommend conditioning systems which will best accommodate them.

Many a sin has been committed in the name of air-conditioning, and the worst offenses are those against humidity.

A relative humidity of about 45% is generally regarded as optimal. Since the water saturation point of air is a function of temperature, the absolute humidity of the atmosphere on a winter day will be much less than the absolute humidity on a summer day, even though their relative humidity may be the same.

In winter the outside air, already low in water content, is brought indoors and heated. While this has no effect on the absolute humidity, the relative humidity is much reduced, commonly to 10% or 15%. This is some 30% short of the required level. The nasal equipment is unable to cope with this drought, the mucus becomes sticky, dry spots appear in the nose and throat, and it is necessary for comfort and health to add water to the atmosphere.

Open pans, employed for this purpose, are seldom capable of evaporating even a small fraction of the necessary amount. Vapor, in the shape of steam or better as finely divided droplets from a mechanical humidifier must be supplied.

Unfortunately, much of this vapor has a tendency to condense on cold window panes, necessitating double-glass sash in the colder climates. In any case, the system must be capable of replacing water lost by such condensation.

The importance of artificial humidification of heated apartments, in the prevention of winter colds, cannot be overestimated.

Summer air-conditioning has often been held responsible for summer colds and kindred respiratory difficulties arising in the hot weather. Some of this criticism is not without justification, but the fault lies with improper conditioning rather than with conditioning *per se*.

Again most of the trouble can be traced to the humidity. The relative humidity of outdoor summer air is high in many communities. When this air is taken indoors and chilled, the relative humidity at the new temperature becomes even higher. In such an atmosphere perspiration does not evaporate readily from the skin. One is aware of a sensation of damp cold, and experiences the usual train of symptoms following chilling. Hence the first consideration in artificially cooled rooms should be the reduction of excess moisture to a level of 45% if possible. In such an atmosphere the evaporation of perspiration can take place, cooling the skin by natural means, and therefore requiring less of a reduction of room temperature to attain the same sensation of coolness.

It is important both for the health and comfort of the individual to bring about the desired effects with the least possible temperature differential between indoors and outdoors. This applies both to summer and winter conditioning.

It is evident from the foregoing that successful air-conditioning depends quite as much on relative humidity as upon relative temperature. First-class heating engineers are thoroughly familiar with these facts and manufacturers of apparatus have made provision for all requirements, in so far as certain mechanical limitations permit. However, unless the installation is competently made the results may still be inadequate. Individual installations should be checked for heat and humidity preferably over 24-hour periods with recording instruments.

It goes almost without saying that vents should be so disposed about the room and the building as to maintain even temperatures. Through improper adjustment and distribution of openings cold air may, for example, settle on the floor while the upper air remains warm, giving the occupants the

sensation of wading in cold water. Injudicious placing of supply and exhaust vents may result in faulty circulation and cause fresh air to be removed while masses of stale air remain behind.

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CHAPTER X

HEATING

TEMPERATURE OF THE PHARYNX—RESPIRATORY HEAT LOSSES—NASAL TEMPERATURE—SINUS TEMPERATURE.

Intimately associated with the process of humidification is that of heating the inspired air. The variations and fluctuations in these two are almost inseparable since both depend upon the blood supply: humidification through the agency of glands, heating through radiation from the vascular network. Just as the alveolar tissues function best under certain conditions of moisture, so also they require relatively constant temperatures.

The temperature of inspired air as it reaches the glottis varies slightly with the temperature of the surrounding air, but the variation is practically negligible being less than one degree cooler with the outside temperature at zero than at 25 degrees.

TEMPERATURE OF THE PHARYNX. Traina[1] records the following temperatures in the pharynx during nasal inspiration at various atmospheric temperatures:

0	inspired	36	expired	36.2
5	"	36	"	36.2
10	"	36.5	"	36.9
15°	"	36.8	"	37
25°	"	36.8	"	37

1. Traina, S. La temperatura dell'aria nella faringe, nelle laringe e nella trachea durante la respirazione nasale e baccale. Arch. de Fisiolog., 29.385-393 (Feb.), 1931.

This indicates a remarkable facility for heating, practically regardless of surrounding atmospheric temperature.

It has been occasionally stated that the nose takes no part in warming the inspired air, but that its function is limited to humidification. The experimental evidence adduced is unconvincing, especially in the light of the foregoing. It is based chiefly upon the fact that the air reaching the pharynx during mouth-breathing is warmed almost as effectively by the mouth as though it had come through the nose. But it does not follow because the mouth is an effective heating device that therefore the nose is not.

As is the case with humidification the exposure of the entire surface is essential for warming. Partial obstructions and deviations confining the air currents to restricted areas result not only in insufficient warming of the air but produce widely diverse temperatures in the various parts of the nasal and pharyngeal mucosa.

The highly efficient system of blood vessels serves a threefold purpose: radiation of heat, the nutrition of glands and the engorgement of the erectile structures. For a detailed description of this vascular network the reader is referred to the abstraction of Swindle's work in a subsequent chapter.

NASAL RESPIRATORY HEAT LOSS. Approximately 2.5% of the heat loss of an average man is accounted for by the nose in heating the inspired air. Helmholtz[2] calculated the heat required in 24 hours to warm the inspired air, with the external temperature at 20°, at 70,000 millicalories (70 calories).

2. Helmholtz, cf. Stewart, G. N.: *Manual of Physiology*, Fifth Edition, Saunders, 1905, p. 502.

		Per Cent	Calories
Skin	Evaporation of Water	15	400
	Radiation	30	750
	Conduction and Convection	35	900
Lungs	Evaporation of Water	15	400
Nose	*Heating Inspired Air*	*2.5*	*70*
	(Heating Excreta)	2.5	70
		100	2590

Analysis of the heat losses of an average man. (Adapted from Stewart.)

The average worker requires from 2,500 to 3,500 calories daily.[3]

NASAL TEMPERATURE. The temperature at any given point in the nasal mucosa fluctuates during the respiratory cycle, being reduced during inspiration by evaporation and increased on expiration by the warmth of the air from the lungs.

Cone,[4] in a group of 75 cases, fixes the "normal" temperature of the inferior turbinate at 32° C. when the oral temperature is 37°. He found patients suffering from acute nasal infection to have a nasal temperature slightly above this (33.8°), in cases of hyperthyroidism 32.6°, of hypothyroidism 30.4°, and of nasal allergy 31.1° C.

These figures although subject to some variation, agree substantially with the previous findings of Schutter,[5] who re-

3. Olmsted, W. H. in Modern Medical Therapy in General Practice, Williams and Wilkins Co., 1940, p. 277.

4. Cone, A. J.: Variations in the Temperature of the Mucous Membrane of the Nose. Arch. Otolaryng., 17:65 (Jan.), 1933.

5. Schutter, cf. Hartz, H. J.: loc. cit.

corded the temperature of the nose as 33° and that of the mouth (in mouth breathing) as 32° C.

Monti and Gregorini[6] found the nasal temperature of 87 nurses in good health to range from 36° to 36.6° C. The description of their experimental methods fails to reveal any cause for the discrepancy of several degrees between their findings and those of the other investigators.

Krukower[7] makes the observation that the temperature of the inferior and middle meatuses rises in the presence of acute maxillary sinus infections; in a unilateral involvement of the maxillary sinus the temperature is higher on the involved side than on the other.

SINUS TEMPERATURE. The temperature within the sinuses varies with the body temperature rather than with that of the inspired air. As a result, it is apt to be increased in the presence of an acute infection, but not in a chronic one.

On cold days the nasal mucosa is subjected to some extremely low temperatures. These are only partly modified by the intermittent warming influence of the expired air. That the surrounding structures, some of them sensitive as for example the eye, the nasal ganglion and the pituitary body, are not subjected to these extremes of temperature may be attributed to two factors. First, the abundant blood supply in the nasal membranes which radiates the required heat through the nose, and second, the insulating effect of the sinuses between the nasal chambers and these sensitive structures. This

6. Monti, P. C., and Gregorini, F. V.: Sulla Temperatura della Mucosa Nasale. Archivio Italiano di Otolgia, Rhinologia e Laringologia, Vol. 51, No. 8, 1939.

7. Krukower, I. M.: Veränderungen der Temperatur in der Nase als Basis für die diagnostischen Verfahren. Monatschr. f. Ohrenh., 63:838 (Aug.-Sept.), 1929.

insulating may be one of the major functions of the sinuses. The fact that tropical animals often have large sinuses does not militate against this idea, since even in the tropical heat a temperature differential between the nose and the other structures is maintained by the evaporation in the nose. Furthermore, the extensive pneumatization of these sinuses practically surrounds the brain and, like a pith helmet, protects it from the heat of the sun. (See Fig. 10.)

The efficiency of the sinuses as insulators is evidenced by the failure of hot applications or even high frequency currents to the cheek to produce any temperature changes in the nose or in the sinuses themselves.

It will be seen from what has gone before that conditions do not exist by which the sinuses could be of any aid in heating the inspired air. Only rarely nowadays do we find any investigator adhering to this theory.

Bronzini[8] asserts that the nasal accessory sinuses serve to warm the inspired air, but that they do not do so simply by contact, as is generally believed. He contends that the air enters the sinuses at the very beginning of expiration and is "warmed, humidified and oxygenated because it has not come in contact with the alveolar tissue but has remained in the uppermost portion of the respiratory tract." He concludes that these cavities constitute a true and proper apparatus of compensation "which modifies the temperature of the inspired air in a manner relatively proportionate to the requirements of the organism."

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8. Bronzini, A.: Physiologic Researches of the Accessory Nasal Cavities. Third Note: The Sinuses and the Temperature of the Inspired Air (Alcune ricerche intorno alla fisiologia della cavita accessorie del naso III. I seni e la temperatura dell'aria di inspirazione). Valsalva, 10:34-39 (Jan.), 1934.

In view of the infinitesimal amount of air emerging from the sinus with each respiration such a theory seems untenable.

Döderlein[9] still believes that the nasal conchae in man have no part in regulating the temperature of the inspired air, but that they regulate only its moisture content.

9. Döderlein, W.: Physiology of Nasal and Oral Respiration: Role of Nasal Sinuses. Ztschr. f. Hals-, Nasen- u. Ohrenh., 30:459 (May 13), 1932.

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CHAPTER XI

ELECTRICAL SURFACE CHARGES

DUST AND SOOT—BACTERIA—ELECTROSTATIC FILTRATION—ADSORPTION.

DUST AND SOOT. Under the conditions of modern life, certainly in the industrial areas, the removal not only of bacteria but also of particulate matter in most finely divided states is important. It has been authoritatively computed that in one such area the annual deposit of solid matter amounted to 900 tons per square mile or roughly one ounce per square foot per annum.[1]

2,500,000 tons of soot are annually deposited on the British Isles according to Professor A. G. Ruston of Leeds University.[2]

The British Medical Journal in 1895 characterized the nose as "in fact one of the dirtiest organs of the body," and suggested that like the teeth it should be washed regularly, using antiseptic solutions in periods of influenza.

Thomson and Hewlett[2] wrote in the same year on the fate of microorganisms in inspired air.

They drew air through their noses and through culture media to determine what effect the nose might have as a filter. The controls in which air was simply drawn through glass

1. Langsdorf, A. S.: The Effect of Atmospheric Smoke Pollution. Mechanical Engineering, Nov. 1927, p. 1213.
2. Thomson, St. Clair: The Defenses of the Air Passages. (Semon Lecture, 1935), Jour. of Laryng. and Otol., 51:1, 1936.

Fig 45. Particles of ash lying on glass slide jump to finger a distance of 5 cm. or more, when the latter bears a surface charge.

tubes "grew 29 moulds and nine bacterial colonies." The air which was drawn through the nose grew only two moulds.

Bacillus prodigiosus spread on the septum could be recovered from it to be grown in culture for 80 minutes but no longer.

Thomson could not confirm the observation of Wurtz and Lermoyez that the nasal mucus exerts a bactericidal influence. It was his impression that lysozone and similar agents play an insignificant part in nasal defense.

Lister noted as early as 1868 that in a simple fracture of the ribs, if the lung was punctured no sepsis occurred through the inspired air. He pointed out that the air had been filtered in its descent through the air passages.

Thomson found that the mucus from the tracheas of animals killed in the laboratory is sterile, and Hildebrandt demon-

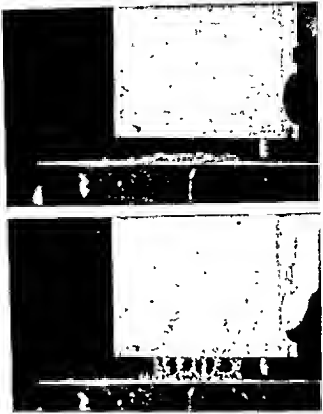

Fig. 46. Experiment to demonstrate adsorption. A vertical aluminum plate is suspended above a horizontal one, and insulated from it by a bakelite rod. Cigarette ash is sprinkled upon the lower plate.

Fig. 47. When, after walking about on a dry carpet, the upper plate is touched, particles of ash rise and cling to it.

strated that the air is freed of microorganisms before arriving at the alveoli.

ELECTROSTATIC FILTRATION. The surface of the human body is the seat of an electrical charge. The entire nasal mucosa being part of the general body surface is likewise

Fig. 48. Graph recording variation in the charge on the mucosa as the subject moves about.

charged. In this case, whatever the initial charge arising from electrolytic causes may be, the tension is profoundly influenced by the friction of clothing upon itself, or upon surrounding objects especially carpets and upholstered furniture.

It is well known that the surfaces of many solids and fluids are in a state of electrical imbalance, that is, they carry a surface charge. It was Faraday who first pointed out that this electrical potential is a surface phenomenon. Hardy and Harvey[3] have shown that the interface between water and air carries such an electric charge. Electrolytic dissociation is credited with producing this charge in some cases, but in others its origin seems to be in doubt. An electronic origin is suggested in view of the fact that various chemical substances, suspensions, emulsions and even filter plugs bear a similar charge of about .04 volts.

More to our purpose is the observation of Rudge[4] on the electrification of dust, of which more presently.

ADSORPTION. According to certain thermo-dynamic phenomena, indicating that any process which diminishes the free energy at an interface will tend to take place (known as

3. Hardy, W. B., and Harvey, H W.: *Surface Electrical Charges of Living Cells.* Proc. Roy. Soc., 84B, p. 217, 1911.
4. Rudge, W. A. Douglas: **On the Electrification Produced During the Raising of a Cloud of Dust.** *Proc. Roy. Soc.* 90A, p. 256, 1914.

Obviously finely divided matter, dust and bacteria, which ordinarily would pass through the nasal airways without being caught are now filtered out by being attracted to the moist nasal walls and held there. When the atmosphere is exceedingly dry, finely divided matter may be attracted over distances much greater than the diameter of the nasal fossa. This may be graphically demonstrated by pulverizing a flake of cigarette ash and spreading it loosely upon a surface at ground potential. If, after walking across the room to build up a surface charge, one approaches the ash with his finger the flakes will jump a gap of two centimeters or more, and cling to the finger.

Some experiments were conducted to demonstrate the nature and extent of the charge and its part in nasal filtration. Electrodes were placed on the body surfaces, including the pharynx and the nose, and the charges found there were recorded by means of a galvanometer. The discharges were often so energetic that it was found necessary to pass them through a high resistance, consisting of a pencil stroke four inches long, drawn upon a block of wood. The slight friction attendant upon the simplest motions produced the curves shown on the accompanying charts.

Obviously, unlike charges must exist between the surface of the nose and the minute air-borne particles in order that filtration may occur.

A filter has recently been placed upon the market to be used in connection with air-conditioning plants, which removes dust from the atmosphere by passing it over highly charged plates. In the course of preliminary experiments with this apparatus it was found that all dust particles did not bear like charges. While this defect could be remedied in the electrical device

by passing the dust over two sets of plates, nasal filtration, unfortunately, is limited to one type of charge.

At the present writing one can only conjecture how important is the part which electrical filtration plays in the cleansing of the inspired air. The fact remains that Linton and others testify to the relative sterility of the posterior half of the nose, which the coarse filtration by the vibrissae and the chance contact of bacteria with the turbinates in passing do not explain.

CHAPTER XII

CILIA—MORPHOLOGY

IMPORTANCE OF CILIA—DISCOVERY 1683—PRIMITIVE STRUCTURES — PROPULSION — VARIABLE MORPHOLOGY —MOISTURE ESSENTIAL — CONTINUOUS STREAM— DIMENSIONS—MORPHOLOGY OF CILIATED EPITHELIUM.

Until recently, cilia have been largely ignored in planning rhinological measures. More by inference than by actual teaching the impression has persisted that cilia are delicate and fragile, that they are vestigial organs and are not to be taken into account. The implication has usually taken the form of ignoring them altogether, from which the student naturally concluded that they are unimportant. In spite of numerous publications of the last ten years, they still fail to appear in the current textbooks to any great extent.

It seems incredible that so important a structure and one daily to be dealt with should be crowded out by lengthy descriptions of rare diseases encountered once in a lifetime.

IMPORTANCE OF CILIA. The fact is that cilia, arising early in the scale of differentiated tissue, are vigorous, and persist in the face of the most unfavorable conditions. They beat under wide extremes of heat and cold. They have been known to beat without special attention as long as 112 hours after death.[1] They may be removed from the cadaver, which has been overnight under refrigeration, and made to beat again simply by warming. They are but little affected by most

1. Ecker, A.: Über das Epithelium der Riechschleimhaut. Freiburger Ber. Nr. *12*. *1935*.

drugs which are heaped upon them. They may beat normally and vigorously in a pus-filled cavity upon a membrane riddled with infection. When injured or destroyed by an acute infection, their regeneration is a matter of hours. When removed en *bloc* with the underlying mucosa down to the bone, the whole structure can be regenerated and function again within six weeks.[2 3] It often happens that cilia persist in beating after the cell to which they are attached is individually teased away from the specimen under the microscope.

DISCOVERY 1683. It was not long after the discovery of the compound microscope that cilia were first observed and described. The credit for the discovery belongs to A. DeHeide,[4] who in 1683 communicated his observations to a world, now for the first time busying itself with the minutiae of nature.

Leeuwenhoek[5] himself described them twelve years later in his Arcana Naturae.

In the melée of descriptive cellular anatomy—plant and animal—which attended the advent of the microscope and the dawn of cytology, the cilia were somehow relegated to the background. It is curious that these spectacular structures which were described even before the nature of epithelium itself was understood, should have attracted so little attention.

In fact, a century and a half went by before any competent work began to be undertaken which would throw some light

2. Knowlton, C. D., and McGregor, G. W.: How and When the Mucous Membrane of the Maxillary Sinus Regenerates: An Experimental Study in the Dog. Arch. Otolaryng., *8:647 (Dec.), 1928.*

3. McGregor, Gregor: Further Proof of the Regeneration of the Mucous Membrane in the Human Autrum. Arch. Otolaryng., 14:309-326 (Sept.). 1931.

4. DeHeide, A.: Anatome Militi, 1683.

5. VanLeeuwenhoek, A.: Arcana Naturae, 1695, p. 48 et seq.

upon their nature and activity.[6] To this day we are indebted chiefly to the comparative zoologists for our knowledge, hence most of the observations are based upon types found in the invertebrates and the amphibia, and our understanding of mammalian cilia is still relatively meagre.

The distinction is more significant than may appear at first glance. Not only are the cilia of various species dissimilar in size and length and thickness, but they function in several media and in fact to several purposes, all of them however propulsive.

PRIMITIVE STRUCTURES. Cilia are very old structures in the history of animal life. They are found in the very primitive unicellular organisms. It is estimated that so simple a protozoön as the paramecium is equipped with some 2500 cilia.[7] In such a case, the organism itself is sufficiently minute to be propelled by the infinitesimal lashings of its cilia, and we find them accordingly fulfilling their first function: propulsion of the animal.

PROPULSION. As we rise in the scale, and the animal increases in size, it is forced either to provide itself with more effective mechanical aids for motion or to remain sessile. In the latter case, cilia can still be effectively employed to waft the surrounding, food-bearing medium into the digestive tract, as for example in the oyster, the sponge, the coral polyp and the star-fish.

This constitutes the second function: propulsion of food. It is not limited, of course, to the sessile organisms. The

6. Sherry, W - On a Certain Movement Brought About in Fluids on the Surfaces of Certain Animals. Edinburgh Med. and Surg. Jour., July, 1830.
7. Bütschli, O.: Braun's Klassen und Ordnungen, Protozoa, 3. Leipzig, 1889.

pharynx and esophagus of the frog and countless other species are similarly equipped. In fact, cilia are entirely lacking only in nematodes and typical arthropods.[8]

Just as food-bearing currents can be propelled to locations favorable to the animal, so waste products and injurious foreign matters—provided they are sufficiently minute—can be transported beyond the zone of their pernicious influence.

This then is the third function of cilia: propulsion of refuse. In the rôle of scavengers, they appear chiefly in the mammal, whose feeding and locomotive requirements are supplied by means more appropriate and adequate to them, but whose more minute channels may still be effectively swept and dusted by this microscopic agency.

VARIABLE MORPHOLOGY. Cilia subserving these several functions, springing from various epithelia, acting in various media, naturally develop characteristics of morphology, size, action and co-ordination of movement in accordance with the demands made upon them. When they are exceedingly long in proportion to their diameters, they are likely to occur singly or in pairs, and to have motions peculiar to themselves. They are then known as flagella. In *mytilus*, an oyster, which depends upon cilia to create a flow of nutrition-bearing sea water, they are slender and maintain a perfection of wave motion—a form and rhythm which is not characteristic of those in the mammalian nose, as will be shown.

In short, there is demonstrable variation between types, sufficient to render one extremely cautious in generalizing from any single observation. One should hesitate particularly to make any deductions regarding the cilia of the human nose from the behavior of any but mammalian respiratory cilia.

8. Gray, J.: Ciliary Movement. Macmillan, N. Y., 1928, p. 1.

MOISTURE ESSENTIAL. The invariable requisite of all ciliary motion is moisture. Nowhere is it encountered on a dry surface. To aquatic animals, submerged in the ocean, this presents no problem. Air-breathing animals living on land are obliged to supply their own oceans, which they invariably do wherever cilia are found, by means of appropriate glands. These coat the surface with an envelope of mucus and give the mucosa its name. Not only are the respiratory tubes covered with moisture, but the pulmonary alveoli as well, for without it the exchange of gases could not be accomplished.

Much has been written regarding cilia in the protozoa, the oyster and the frog; and very little regarding those in the human nose. Only with the gradual recognition of their importance in the defense against bacteria, has come the long delayed interest. Properly enough, the work is now being pursued by rhinologists and those closely associated with them, whose interests are essentially clinical.

One has but to watch on a fragment of diseased tissue freshly removed at operation the vigorous, almost primordial struggle of the cilia against odds, in order to convince himself of the importance of preserving, maintaining and strengthening this first-line defense which nature has so effectively established along one of our most belabored frontiers.

CONTINUOUS STREAM. The nasal ciliated epithelium constitutes in the normal human nose a continuous covering, which lines the nasal chambers, the ostia and the sinuses in one unbroken sheet. It is wanting in only two locations, the olfactory area and the pre-turbinal area.

Ciliary streaming is invariably toward the pharynx. The overlying blanket of mucus always moves from the more re-

mote areas of the sinuses, toward and through the ostia, thence backward through the meatuses to the epipharynx. Here its progress is taken over by the muscles of deglutition, as the ciliated cuboidal epithelium merges into the squamous.

The journey from the remotest corner of the farthest sinus to the pharynx consumes about twenty minutes. From the standpoint of protection, the time element is of importance since most pathogenic bacteria are thus disposed of before they can injure the host.

DIMENSIONS. Cilia vary from .1 to .3 μ in diameter and up to 15 μ in length.

Human nasal cilia are approximately 7 μ long—which is about the diameter of an erythrocyte—and less than .3 μ in diameter. They are packed as closely as the pile of a carpet. They are slightly curved near the free end, in the direction of beat. Slow-motion pictures under high magnification indicate that this curve is not entirely lost as the cilium moves hack and forth. The path which it describes may be likened to that of a sickle in the hand of a reaper.

MORPHOLOGY OF CILIATED EPITHELIUM. While cytologists are not at one regarding the structure of the shaft of the cilium, the preponderance of opinion seems to be that it shows no differentiation of structure even under polarized light. The same is true when seen against a dark field.

Gray[9] believes with Mackinnon and Vlès[10] that an apparent double refraction under polarized light, described by

9. Gray, J: Ciliary Movement. Macmillan, N. Y., 1928, p. 9.
10. Mackinnon, D. L., and Vlès, F.: On the Optical Properties of Contractile Organs. J. Roy. Micro. Soc., 553, 1908.

Englemann,[11] is due to diffraction at the surface of the cilium and not to its internal structure.

The superficial layer of the nasal epithelium is composed of two kinds of cells, ciliated and mucous. In some areas, one predominates, in some the other. The type which happens to be in the minority is not distributed evenly among the predominating cells, but appears in small groups. In the nose the ciliated cell is the predominant one. Under certain conditions, however, such as the diversion of air currents which results when a tracheal cannula is worn, mucous cells may increase until they predominate.

The epithelium contiguous to the mucous glands is ordinarily slightly thicker than the rest, and cilia extend for a short distance into the lumen where they assist in the expulsion of mucus from the duct.

It is obviously a difficult task to determine the number of cilia upon the surface of a cell. Lucas,[12] who examined a cell surface 6.2 μ in diameter found there 8.5 cilia. He found also that the distance between the cilia is approximately equal to their own diameter.

At the attachment of the cilia and lying close to the cell membrane within the cell are minute spherical structures known as basal bodies from which rootlets extend into the cytoplasm to the region of the nucleus. Immediately beneath these bodies is a clear zone in which the cytoplasm is free from granules.

The cell attachments of the cilia and the related intracellular structures vary with the location and the species. The

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11. Englemann, T. W.: Dictionnaire de Physiologie, Paris, 1898.
12. Lucas, Alfred, in Cowdry, E. V.: Special Cytology, Second Edition, Hoeber, 1932, p. 409.

Fig. 50. Nasal Ciliated Epithelium. Respiratory portion. In order to obtain a clear conception of both the architecture and the activity of this tissue it is necessary to study stained specimens such as the above, living tissue shown on the opposite page, and motion pictures. The stained specimen is best for detail. It shows the arrangement of the cells and their nuclei, and something of the granular material. But owing to the staining and fixing processes the cells are attentuated, the nuclei are disproportionate, and the cilia are shrunken and in disorder. This gives no impression of their shape, stroke, or coordination. (Photomicrograph, X1500.)

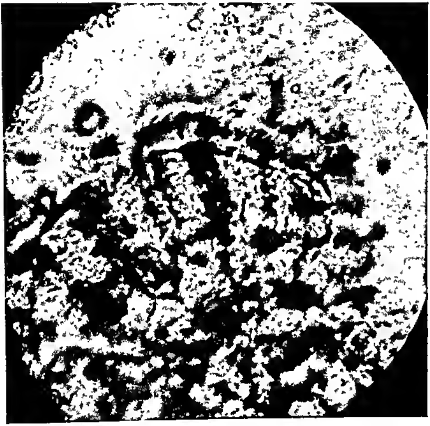

Fig. 51. Nasal Ciliated Epithelium. Respiratory portion. Living tissue unstained. Ciliary motion has been momentarily arrested by chilling the slide with ethyl chloride. Although it is difficult to obtain definition in such a preparation, it shows to advantage the natural outlines of the cells, the positions of the nuclei, the distribution of the granules, and particularly the vital characteristics of the cilia: shape, size, relations, distribution, motion. The erythrocyte, upper left, supplies a convenient scale. (Photomicrograph, X1600.)

arrangement in the nose and sinuses is fairly typical. The fibrils which are not constant throughout nature appear to be so in the nose.

In living specimens the cilia are thicker than in stained specimens and the spaces between them are practically obliterated. (See Fig. 51.)

The ciliary rootlets terminate in the cytoplasm near the nucleus. The co-ordinative impulses, whatever their nature, traverse the cytoplasm of the cell and it is by means of the system of diverging rootlets that the impulse is transmitted simultaneously to all the cilia upon a single cell.[13]

This is not unlikely the basis for the crescentic group movements and the "dimple waves" found in human membranes where the wave continuity is less apparent.

It is Hilding's observation that the type of epithelium to be found in the nose and the sinuses depends somewhat on the degree of exposure to which the surface is subjected. The relatively cuboidal cells of the sinuses tend to become columnar if the ventilation is increased. If the surface is actually exposed to blasts of air the epithelium becomes stratified and the cilia disappear.

Sternberg[14] maintains that the goblet cell is identical with the ciliated epithelial cell and that the change in morphology is in response to varying functional needs.

13. Lucas, Alfred M.: An Investigation of the Nervous System as a Possible Factor in the Regulation of Ciliary Activity of the Lamellibranch Gill. J. Morph. and Physiol., 51:147 (Mar.), 1931.

14. Sternberg, H.: Physiology of the Mucosa (Beiträge zur Physiologie und pathologie der Schleimhaut der Luftwege). Zeitschrift für Hals-Nasen und Ohrenheilkunde, 1924.

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Mollendorff, W. V.: Handbuch der Mikroskopischen Anatomie Des Menschen, p. 52 et seq.

CHAPTER XIII

CILIA—ACTION

"EFFECTIVE" AND "RECOVERY" STROKES — WAVE MOTION — SPEED AND FREQUENCY — THE MUCOUS BLANKET — CILIARY PATHWAYS — PATHWAYS IN THE SINUS—MUCUS IN TUBULAR FORM—PATHWAYS IN THE BRONCHI—EXAMINATION OF LIVING CILIA IN SITU—NATURE OF CILIARY IMPULSE—NATURE OF WAVE CO-ORDINATION—ENERGY.

"EFFECTIVE" AND "RECOVERY" STROKES. The forward and backward movements of a cilium have been designated the "effective" stroke and the "recovery" stroke.

This type of motion is universal among cilia, although several other patterns are common to the flagella.

The effective stroke, as its name implies, is the propulsive phase. It is much faster and more vigorous than the recovery stroke. It is variously estimated as occupying from one-third to one-fifth of the cycle.

During the effective stroke, the nasal cilium is stiff and its tip curves in the direction of beat, giving it a hooked appearance in profile. During the recovery stroke, it is relatively limp. Both strokes are in the same plane.

The path described by an individual cilium varies somewhat with its place in nature, its dimensions and its function. The author's own observations of cilia seen by reflected light in the sinuses of living mammals (rabbit, guinea pig) and the

recently extirpated tissues of man, suggest that there is less freedom of motion here than, for example, in those from the gills of *mytilus*. Wave motion is less continuous, and the appearance is rather that of myriads of hands clutching than of grass waving in the breeze. This is the result of crescentically arranged clumps of cilia, each clump giving every indication (under high power, high speed cinemicrography) of moving independently of its neighbors. The effective beat, to be sure, is all in one direction, but wave propagation appears on the

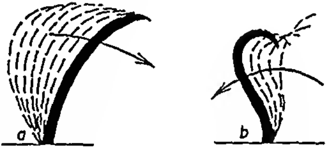

Fig 52. Diagram showing the character of a, the effective stroke, and b, the recovery stroke, in a human nasal cilium.

whole to be occasional and the result of many small movements frequently synchronizing.

Wave Motion. Early studies of wave motion, made by Kraft[1] with a stroboscopic apparatus, established many of the now accepted characteristics of ciliary action.

Ciliary wave forms are of several types and vary likewise with the tissues in which they are found. They are quite constant however for any given tissue. In *mytilus* and similar

1. Kraft, H.: Zur Physiologie des Flimmerepithels bei Wirbelthieren. Pflüger's Archiv., 47:196, 1890.

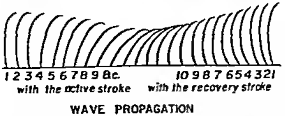

Fig. 53. Diagram showing the nature of a continuous wave.

Fig. 54. Diagram showing the nature of wave propagation. If the succession of beat follows the active, or effective stroke shown at the left, the crest progresses in the same direction as the streaming. If the succession follows the recovery stroke, shown at the right, the crest progresses in the direction opposite to the streaming.

marine forms there occur beautifully regular progressions from end to end of the specimen which have the characteristics of wheat blowing in the wind. The direction of wave progression is also usually constant for a given tissue. It may be in the direction of the effective stroke, or of the recovery stroke, or even laterally.

In the human nose, and in other vertebrates (monkeys, rabbits, guinea pigs) the wave progression is in the direction of the recovery stroke. That is, if ten adjacent cilia are numbered (left to right) from one to ten, and the effective stroke, hence the streaming, is from left to right, then the "firing order" will be 10-9-8-7-6-5-4-3-2-1. Seen in profile, the surface stream moves from left to right, the wave from right to left.

Möllendorff and some others are not in agreement with this statement.

Fig 55 Normal nasal mucosa *in a living rabbit.* (As reproduced, enlarged 416X)

When, by means of a special microscope with an opaque illuminator, slow-motion cinemicrographs are made of these waves, looking down upon them, one is immediately struck by the broken character of the movement. While the membrane is moist, the surface presents a series of dimples moving across the field in one direction.

These dimples do not pass continuously across the whole length of the field, but each individual dimple is of short duration. It appears as a shallow pit, rapidly increases in depth and width and as rapidly decreases and disappears, traveling only a few times its own diameter. Succeeding dimples do not always have their origin in exactly the same spot.[2]

As the specimen dries ever so slightly, the cause of the dimpling is seen to be the beating of crescentic clumps of cilia, each clump acting more or less independently of the rest. So many groups beating in one direction at a nearly uniform rate

2. Proetz, A. W.: Five Preliminary Notes on Nasal Function. Ann. of Otol., Rhin. and Laryng., 41:1117, No. 4 (Dec.), 1932.

Fig 56. Human maxillary mucosa, showing ciliary activity at points where the light is reflected The mucus in the shaded area obscures it. (Magnification 40 X)

Fig. 57. Portion of Fig. 56, showing the form of the ciliary propulsion (Magnification 636 X.)

Fig 58. Short wave forms These are scarcely waves at all, but irregularities produced by the pulsations of groups of cilia.

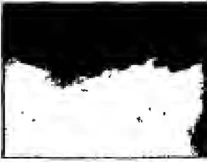

Fig 59. Ciliary pulsations seen through the blanket of mucus.

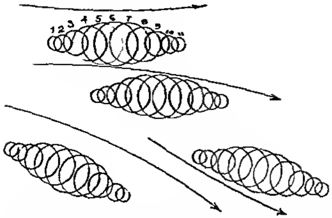

Fig. 60. Diagram to show the appearance of local, or "dimple" waves. They appear as minute depressions in the mucus blanket which rapidly broaden and deepen and as rapidly disappear. The cycle requires only a small fraction of a second.

frequently have the appearance of long crests, but these are not constant for a given area.

Gray states that nearly all observations of ciliary movement are made upon tissues whose activity has through the exigencies of the experimental conditions been artificially subdued. There seems to be little difference, however, between the slow motion thus produced and the merely apparent slow motion of the cinematograph which is a true representation of physiological motion.

Much greater co-ordination of ciliary movement occurs in the invertebrates than in the higher animals according to Gray. The author's own observations are in accord with this especially in the production of "dimple waves."

Speed and Frequency. The frequency of the ciliary beat varies with conditions, in the human chiefly those of tem-

perature. At the normal nasal temperature of about 30° C. which appears to be the optimum for cilia in that location, the beats occur from 8 to 12 per second.

Gray estimated the speed of the beat as follows: "Let the length of a cilium be 10 μ and let it oscillate through an amplitude of 180° twelve times every second; the total distance travelled in one second by the tip of the cilium is therefore $12 [\pi (10 \mu)] = 375 \mu$ (approx.)."

Accepting Kraft's[3] estimate that the velocity of the effective stroke is five times that of the recovery stroke, the tip of the cilium will move approximately 1 mm. a second, or 12 feet per hour.

The author's own observations suggest that in the human nose the effective stroke occupies somewhat more than 1/6th the time of the cycle, and that the arc traversed is considerably under 180°. With a radius of 7 μ instead of 10 μ, the resultant speed would therefore be much less than that of Gray's example.

The rapidity of motion depends only partly upon the temperature. The moisture, the viscosity of the mucus and, in the extirpated specimens, the time elapsed since removal are factors. The removed specimens on the whole survived depressions of temperature much better than relatively smaller increases. It was not possible in any of the author's experiments to verify Wharton's[4] observation of the retarding effect of light. In the early experiments it was suspected that a slowing action of some kind was at work which, since it disappeared

3. Kraft, H (cf Gray): Zur Physiologie des Flimmerepithels bei Wirbelthieren. Pflüger's Archiv, 47, 196.
4. Wharton, D. R. A.: The Effect of Certain Toxic Substances on the Ciliated Epithelium of the Guinea Pig. Am. Jour. of Hygiene, 14:109, 1931.

on shutting off the light, corresponded fairly accurately to Wharton's description. However, the introduction of a cooling chamber between the source of light and the specimen terminated the phenomenon, which was therefore attributed to heat.

The speed of the individual cilium, however, is of less importance to the rhinologist than the speed of the streams which are set up in the overlying mucus. This has been variously estimated at from .25 cm. to .75 cm. per minute although in certain experimental conditions it may be much slower.

The significant conclusions to be derived from these figures, are, namely, that a sinus with its full complement of cilia can renew its mucous coating in the short space of some five or ten minutes and that the entire nasal blanket is discarded into the pharynx at the rate of at least once every half hour!

This so-called "ciliary streaming" is not uniform in all parts of the nose either in its vigor or its speed. As a general rule, the ciliary beat, and hence the streaming, is more active in the protected recesses of the meatuses than in the exposed portions such as the edges of the turbinates and the septum.

According to Hilding[5] the speed of motion is comparatively rapid in the posterior two-thirds of the nose, where it may reach 10 mm. a minute. In the anterior third, where the air strikes the mucous membrane more directly, the speed is much slower. This is, no doubt, partly accounted for by the fact that the mucosa in the preturbinal areas is not ciliated, and the mucus in these regions is drawn backward by remote traction.

5. Hilding, A.: Direction and Rate of Drainage of Mucus Secretions from the Internal Surfaces of the Nose. Proc. Staff Meet. Mayo Clinic, Vol. 6, No. 19 (May 13), 1931.

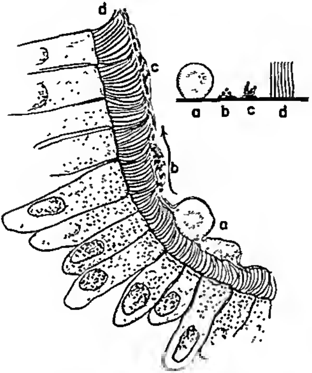

Fig. 61. Diagram of several foreign bodies enmeshed in the mucus blanket, and being carried uphill by the cilia. a, an erythrocyte; b, cocci; c, bacilli; d, cilia.

Within the frontal sinus the rate of flow varies from 2 mm. to 18 mm. a minute and in general it increases as the ostium is approached, the highest rate being at or within the opening. The streaming is quite independent of gravity, the swiftest streams often traveling directly upward.

Activity and speed of travel are commensurate with those found in the lung where india ink has been seen to move approximately 1 cm. in four minutes in the bronchioles, and 1 cm. in one minute in the trachea. Ink injected subpleurally

into the lungs of decerebrate cats was carried to the subglottic region in 14 minutes, a straight-line distance of about 12 cm. As the streaming within the trachea and the bronchi is a spiral one, the total distances traversed by the ink were even greater.[6]

THE MUCOUS BLANKET. The mucous blanket which constitutes the actual conveyor of the system has received scarcely a tithe of the recognition which its importance demands. It has four essential attributes of clinical importance: it is exceedingly thin, slippery, adhesive and tenacious.

It is so thin as to be invisible in the normal nose, although it may be picked up at any point, like a spider web, with a capillary pipette.

It is so adhesive that particulate matter is firmly held on slight contact. A whiff of cosmetic powder inhaled while dusting the face is deposited in the anterior half of the nose. Rarely does it penetrate to the choana or the pharynx.

It is so slippery and tenacious that the mucus of the preturbinal area, in which there are no cilia, is drawn away in a sheet by the cilia farther back, thus cleansing the area. In the author's investigations, it has been possible to restrain the progress of the blanket at one edge of the field allowing the cilia to tug at it and stretch it until it finally snapped like a rubber band.[7]

While this structure *in situ* lends itself readily to observation and description, it is singularly elusive to research *in vitro*. (See Chap. XVI.)

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6. Barclay, A. E., and Franklin, K. J.: The Rate of Excretion of India Ink Injected Into the Lungs. J. Physiol., 90:482, 1937.
7. Proetz, Arthur W.: Nasal Ciliated Epithelium, with Special Reference to Infection and Treatment. Jour. of Laryng. and Otol., 49:557 (Sept.), 1934.

Fig. 62. Sequence from a motion picture film showing the tenacity of the mucous blanket. Carbon granules were strewn upon the blanket to bring out its movement; on restraining the blanket below, the cilia tugged at it from above until it stretched and finally snapped. This explains how localities without cilia, or temporarily deprived of them, can be cleansed by the action of adjacent areas.

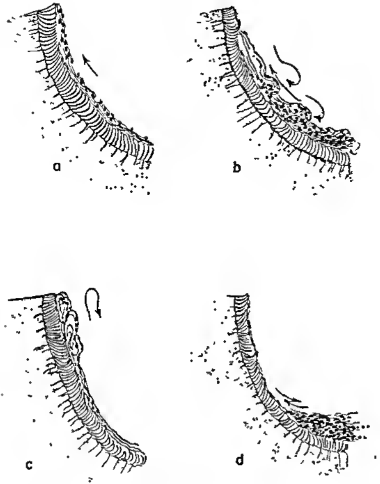


Fig. 63. Diagrams illustrating the behavior of the mucous blanket in various situations

a. Normal ciliary streaming.

b. The rolling over of tbe mucos in masses, which occurs when it is too viscous, and excessive in amount

c. Similar behavior of the mucus when it reaches an area denuded of cilia, or the margin of a surgical opening.

d. A situation in which the mocus is present, but is watery, and not of sufficient viscosity to form a blanket. It gathers at the bottom of the cavity. If bacteria are present they are washed down with it.

Springing from the glands with which the mucosa is so richly supplied, the mucus is picked up by the cilia in the mouths of the ducts and passed along to the pharynx. The olfactory area in man has glands but no cilia. A small preturbinal area likewise has glands but no cilia. Elsewhere the mechanism is complete. At the level of the nasopharynx be-

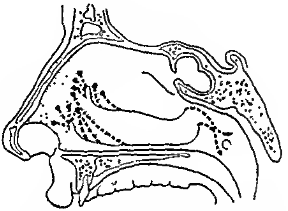


Fig. 64. Courses of the currents of secretion from the inactive areas on the anterior third of the lateral nasal wall. (From Hilding, with his kind permission.)

low the pharyngeal tonsil the ciliated epithelium merges into the squamous type.

Ciliary Pathways. Lowndes Yates[8] in 1924 published his work on the ciliary pathways, which was important not merely for its intrinsic information but for the fact that it stimulated a widespread renewal of interest in nasal cilia in general. His now familiar descriptions of these pathways have been verified by many other observers.

8. Yates, A. L.: Methods of Estimating the Activity of the Ciliated Epithelium Within the Sinuses. J. Laryng. and Otol., 39:554, 1924.

The streaming from the middle meatus passes chiefly along its upper part emerging beneath the posterior tip of the turbinate, and passing down in front of the eustachian tube. Material from the posterior ethmoid sinus escapes from the superior meatus and proceeding downward, divides into two streams, passing before and behind the opening of the eusta-

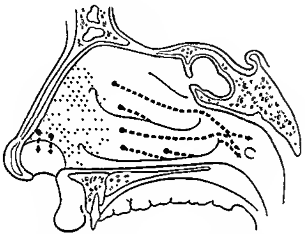


Fig. 65. Courses of currents of secretion from the active areas on the lateral wall of the nose. (From Hilding, with his kind permission.)

chian tube, and rejoining below it. Material from the sphenoid sinus passes directly downward, turning backward and spreading fanwise over the vault of the nasopharynx, or down the posterior margin of the septum as a thread. In the pharynx, it again finds the lateral wall though this last is the result of the wiping action of the palate, since the cilia do not extend so low.

Hilding[9] points out that practically all the drainage from the anterior third of the membrane on the lateral wall passes

9. Hilding, A.: Influence of Ciliary Activity on the Bacteriology of the Nose. Proc. Staff Meet. Mayo Clinic, Vol. 6, No. 19 (May 13), 1931.

through the middle and inferior meatuses. The streams, as they leave the posterior confines of the meatuses, tend downward and backward into the nasopharynx, dividing in order to avoid the opening of the eustachian tube.

Bryant's contention that the streaming in the nose is toward the nostril has found no corroboration by others. His experiments were performed with pieces of mucosa removed from human turbinates at operation, and the motion was indicated by small pieces of rubber dam laid upon them.[10]

Unlike man and monkey the direction of the mucus flow in the upper one-half to two-thirds of the lateral wall including the middle meatus, is forward in mouse, rat, rabbit, opossum, cat, sheep and cow. The material from the maxillary sinus is spread fanwise to the nostrils, floor and nasopharynx.[11]

Thus again, one cannot assume that conditions found in animal experiments apply to humans.

This circumstance together with the fact that even in the human, streaming is not always in straight lines to the pharynx, but sometimes wanders about for short distances, may have been the basis for Bryant's experience.

Lucas[12] found that in the monkey the olfactory area is entirely devoid of cilia as is the case in man. In compensation for this, the ciliary movement at the border of the olfactory

10. Bryant, W. S.: An Experiment to Prove that the Cilia of the Human Nose Waft Toward the Anterior Nares. Am. J. Physiol., 33:430 (Mar.), 1914.

11. Lucas, Alfred M., and Douglas, L. C.: Direction of Flow of Nasal Mucus. Proc. Soc. Exper. Biol. and Med., 31:320-321, 1933.

12. Lucas, A. M.: Direction of Ciliary Movement in the Nasal Cavity of Macacus Rhesus (Demonstration). (A Preliminary Report.) Trans. Amer. L. R. O. Soc., 1931, p. 172.

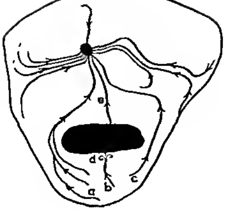


Fig. 66 Diagram showing typical pathways of ciliary streaming in the sinus. These all lead to the ostium, but not always in a straight line. Although the large surgical opening shown below lies in their direct path, particles placed at a and c avoid it in reaching the ostium. Particles placed at b encounter the cut edge at d and fall back into the sinus. Particles placed at e do not stream toward the larger opening, but follow their customary path through the ostium.

epithelium is practically perpendicularly away from the margin.

PATHWAYS IN THE SINUS. Ciliary streaming in the sinus always leads to the ostium—but not always by the shortest route. If a foreign particle is placed in a given spot, it invariably reaches the ostium by the same path, circuitous though it may be.[13]

It has been noted by several observers that particles placed in various locations within the sinus do not reach the ostium

13 Hilding, A. The Influence of Ciliary Activity on the Bacteriology of the Nose: Direction of Ciliary Currents in the Frontal Sinus of the Dog Proc Staff Meetings of the Mayo Clinic, Vol. 6, No. 21, 1931; also, The Physiology of Drainage of Nasal Mucus. Arch of Otolaryng., 15 92 (Jan), 1932.

with the same speed, that is to say, there are certain "express highways" in the sinuses, just as there are in the nose.

King has verified clinically the observation of Hilding that a maxillary sinus, even after an opening into the inferior meatus has been made, empties itself through the ostium if the cilia are functioning. He makes a practice of testing this function clinically by instilling a small quantity of iodized oil into the antrum and watching the pathways of evacuation per roentgenograph.[14]

Hilding[15] cut strips of the mucosa away from the lining of the frontal sinus in the dog in such a manner as to block the normal ciliary pathways. This eventuated in high ridges and diaphragms of scar tissue which, however, interfered with drainage only when they were so placed that the mucus could not readily slide around them.

MUCUS IN TUBULAR FORM. If one conceives of the mucus which lines the sinus as moving from all walls toward the ostium and emerging from it into the nose, then theoretically it should assume the form of a hollow rope or tube. In the normal nose, the thinness of the blanket relative to the size of the ostium is such as to render the tube undemonstrable, but the author has succeeded in demonstrating such formations when the mucus was unusually thick and abundant. In some subjects, excessive quantities of abnormally tenacious mucus are extruded from the sinuses following the ingestion of alcohol. In others, it may be the result of infection. In any case, if one of these gelatinous masses is removed from the floor of the

14. King, Edward: A Clinical Study of the Functioning of the Maxillary Sinus Mucosa. Ann. of Otol., Rhin. and Laryng., 44:480 (June), 1935.

15. Hilding, A.: Experimental Surgery of the Nose and Sinuses. II. Arch. of Otolaryng., 17:321 (Mar.), 1933.

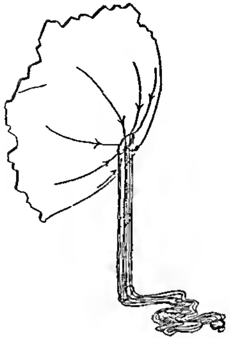


Fig. 67. Diagram showing how secretions coming from an ostium can form a rope or a tube.

nose and dropped into water, it promptly unfolds into a semi-transparent rope.

If the mass is dropped instead into formalin, it can be more readily manipulated. When some dark material, such as one of the silver proteins has previously been used in the sinus, the "rope" can be seen under the microscope to be made up of concentric layers.

PATHWAYS IN THE BRONCHI. Even in the trachea and bronchi (sheep, dogs, cats) ciliary streaming does not travel the shortest distance to a point. Generally speaking, it is spiral. At the junction of bronchi the streams avoid the actual

edge of the junction, passing to left and right and joining a spiral streaming in the larger bronchi or the trachea. This spiral approaching the glottis, rotates clockwise, as viewed from above.[16]

The observation of cilia under the microscope is a very simple matter. A small strip of membrane is removed and folded upon itself so that the cilia standing free from the folded edge may be viewed in profile. The tissue must be kept constantly moist with physiological sodium chlorid solution, or better with Ringer's or Locke's solution. No special precautions with regard to temperature are necessary, although extremes should be avoided.

The readiest source of material is probably the surface of the adenoid. This should be placed in the solution as soon as it is removed.

It may be that many observations, under experimental conditions, give one an exaggerated impression of ciliary activity, in that the stimulating effects of instrumentation and fluids accelerate the beat,[17] although Gray believes the reverse may be true. There are many factors which influence speed and it is not unlikely that either acceleration or slowing may characterize a given experiment according to the accompanying circumstances.

The author has not had the experience of Schumacher[18] that the artificially isolated fragments of cilia roll themselves into balls, cilia side out. On the contrary, he has sometimes

16. Barclay, A. E., and Franklin, K. J., and Macbeth, R. G.: A Contribution to the Study of Ciliary Movement. J. of Physiol., 90:347, No. 3, 1937.

17. Lucas, Alfred M: Comparisons of Ciliary Activity Under in Vitro and in Vivo Conditions. Proc. Soc. Exper. Biol and Med, 30:501-506, 1933.

18. Schumacher, S.: Zur Biologie des Flimmerepithels. Sitzungsber. d Akad. Wien, Mathem-naturw. Kl. III. Bd. 100, S. 195-224, 1901.

had great difficulty in identifying anything but fibroblasts in the tissue fragments because the cilia were curled inside. The student, unaware of this, may examine many fragments without seeing any cilia until he learns to tease these bundles apart.

It has been suggested that the behavior of these balls is somewhat dependent upon conditions of osmotic pressure, temperature and light.[19]

From the usual profile view one derives a fairly accurate impression of the size, shape and behavior of the individual cilium. Where the cilia are spread over a surface instead of being arranged single file as in *mytilus* an edge view is apt to give an imperfect picture of the true wave form. For this purpose a vertical or "bird's-eye" view is necessary and special means must be employed to obtain it.

For the convenience of the student a short description of the author's apparatus follows:[20]

For experiments using the living animal the stage, condenser and substage mirror of the microscope are removed. The condenser carrier, with its elevating and lowering rack and pinion, is retained and into this is fitted a clamp for fixing the rabbit's head in position. If it is not required by the experiment that an animal be used these changes in the microscope are unnecessary, a strip of excised membrane being mounted on an opaque material and clamped to the stage in the usual manner. A Leitz "Ultropak" vertical illuminator with a 6.5 objective is employed, together with a 16X ocular. This combination insures sufficient depth of field. A firmly

19. Zweibaum, J.: Sur la survie de l'epithelium vibratile in vitro. Cpt. rend. des séances de la soc. de biol. Bd. 93, S. 782-784, 1925.

20. Proetz, A. W.: Studies of Nasal Cilia in the Living Mammal. Ann. of Otol., Rhin. and Laryng., 42:778, No. 3 (Sept.), 1933.

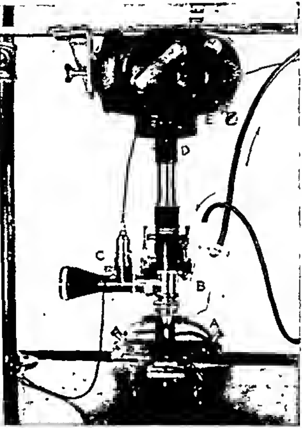


Fig. 68. Apparatus for examining and making motion pictures of nasal cilia in the living mammal.

A—Movable stage with clamp for holding head.

B—Capillary tubes for supplying and withdrawing fluids.

C—Opaque illuminator.

D—Reflex focusser.

E—Motion picture camera.

supported, quickly adjusted motion picture camera, with reflex focuser, completes the equipment.

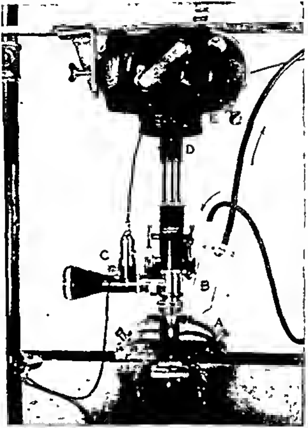
EXAMINATION OF LIVING CILIA IN SITU. In preparation, a rabbit is anesthetized with a peritoneal injection of urethane to the point of complete analgesia. The clamp is removed from the microscope, and the animal's head securely fastened in it. A midline incision follows the bridge of the nose through its entire length, and the periostium is elevated. Sutures through each side tied to the screws of the clamp serve as retractors. A chisel removes the bone, covering one nasal chamber, without perforating the nasal mucosa. This is not at all difficult.

Before proceeding all bleeding must be stopped by means of pressure, and the field cleaned with the aid of suction. Styptics and constrictors must be avoided. The membrane lying above the part to be studied is now removed with a cataract or a paracentesis knife, the small flow of blood being taken up with the suction tip. The opposite side of the nose is undisturbed and is to be examined as a control at the end of the experiment.

The clamp with the rabbit in it is now attached to the microscope. What ensues is apt to be tedious, namely the search for an area of such a topography that it will reflect high lights into the objective.

While the search is going on, in fact as soon as the sinus is opened, moisture must be frequently supplied to the membrane or the surface will dry out and the whole experiment fail.

This is best accomplished by means of a pair of glass tubes bent and welded together to form a Y the double stem of which has been drawn out into twin capillary tubes.



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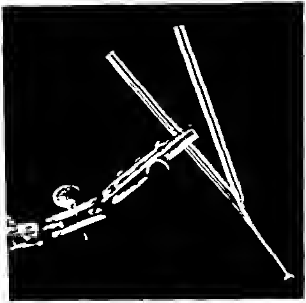

Fig. 69. Double capillary tube for manipulating fluids on the surface of the mucosa, in the microscopic field.

Immediately after the sinus is opened the double capillary tip is lowered into it almost touching the membrane and is fixed in this position by means of a suitable clamp.

One arm is attached to a suction pump and *gentle* continuous suction is established. Fluid is then fed into the other arm through a capillary pipette. It flows onto the membrane through one capillary tip but is immediately taken up by its twin which is connected to the suction pump. Thus fluid can be applied and withdrawn at will without flooding the sinus and choking the animal and without obscuring the field.

Owing to the mucus blanket the ciliary movement cannot be seen everywhere. It is necessary to single out a small ridge

in the membrane (fortunately the rabbit has several of these) from which a spot of light is reflected into the objective. At the margin of such a spot where the light strikes the membrane obliquely the cilia are brought into prominent relief.

Once the area is selected, the twin capillaries are brought to the edge of the field, just avoiding contact with the membrane.

This twin capillary tube device fills many needs both in the simple maintenance of moisture and in the study of local drying, temperature changes and drug effects. It is made in the following manner:

Two pieces of small glass tubing, approximately eight inches long, are held together so that the middle of each crosses the other at right angles. The flame of a gas blow torch is allowed to play across the junction until the tubes adhere to one another and finally soften. The tubes, still crossed, are then grasped by their ends so that each hand holds one end of each tube. Thus they form an X the middle of which is in a state of flux. The hands are now separated until the softened glass is drawn to a double capillary tube. Each hand now holds a Y-shaped apparatus of which the arms are glass tubes, and the stem a double glass capillary.

The points of junction should be held for a time over the flame and allowed to cool slowly in order to anneal the glass, otherwise the tubes may crack or separate while in use.

Nature of Ciliary Impulse. Whether the cilia are units capable of independent motion, or whether they are activated by the cell, has not been determined although both views have their proponents.

It is generally conceded that most cilia, when separated from their cells, are motionless.

The author has seen individual cells, teased away from the tissue cultures, propelled about in the fluid medium by their cilia. These cells assume a more globular form than their attached neighbors and remain active for indefinite periods.[21]

The forces which control the co-ordination and wave form of the ciliary beating likewise remain a mystery. Nor is it for want of investigators that this is so. The evidence is conflicting and not always unimpeachable. However, as Gray aptly puts it, "When we remember that really nothing is known of the machinery whereby a muscle develops a tension when it is stimulated, it is not surprising that the ciliary mechanism also remains obscure."[22]

Except for a very few attempts with slow-motion cinemicrography, observers have been compelled to base their theories upon a comparison of motion seen fleetingly in living tissues, with structure as revealed in the stained specimen.

None of the better known hypotheses fit all of the known facts. Shäfer[23] in 1891 reasoned that if the shaft of the cilium were a hollow curved extension of the cell itself, and hence invested by the elastic cell membrane, and if through a rhythmic contraction and relaxation of the cell it were alternately distended and collapsed, movement would result in it similar to that observed under the microscope.

21. Proetz, A. W., and Pfingsten, M.: Tissue Culture of Nasal Ciliated Epithelium. Arch. of Otolaryng., 29:252 (Feb.), 1939.
22. Gray, J.: Ciliary Movement. Macmillan, N. Y., 1928, p. 7.
23. Shäfer, E. A.: On the Structure of Ameboid Protoplasm and a Suggestion Regarding the Mechanism of Ciliary Activity. Proc. Royal Soc., 49:193, 1891.

But since the contraction, forcing the hyaloplasm from the cell into the cilium, would under such a hydraulic system tend to straighten out the cilium, it would follow that the distension would have to be slow and the relaxation fast, since the velocity of the effective stroke is greater than that of the recovery stroke. In this case the propulsive force of the cilium would be due entirely to the elastic strength of its membrane. A tubular structure having one distensible and one non-distensible side might conceivably bend over toward the latter under internal pressure; but there is no evidence to date that cilia are hollow, nor has any other structural differentiation been detected in them.

Another hypothesis, accepted by many authors, is that of Heidenhain,[24] who attributes the motion of the cilium to rhythmic contractions of one side of the supercificial layers of the shaft, which also presupposes the rigidity of either a central core or the opposite side.

Thus one hypothesis rests upon others for which no evidence exists.

NATURE OF WAVE CO-ORDINATION. There is no more agreement regarding the mechanism by which wave movements are co-ordinated. Here again we must fall back upon zoölogists for our experiments and for the present be content to accept the evidence in terms of frogs.

All are agreed that nerves in some way modify the rate of ciliary movement in the palate of this animal. McDonald, Leisure and Lenneman[25] regard the cilia as constantly active.

24. Heidenhain, M.: Plasma und Zelle. 1, 2 Jena, 1911.
25. McDonald, J. F., Leisure, C. E., and Lenneman, E. E.: Proc. Soc. Exp Biol. and Med. 24:968, 1927; Trans. Am. Acad. Ophthal. and Otolaryng., 34:318, 1928.

They assert that electrical stimulation of the sympathetic trunk and also epinephrin and ephedrin (sympathomimetics) accelerate the movement, while the parasympathetic nerves and pilocarpin (parasympathomimetics) serve to restrain it.

Lucas[26] questions their findings on the ground that they used as indicators foreign bodies which in themselves may stimulate the cilia. After observing the surface by reflection without solid indicators, he has concluded that fibers in the palatine nerve of the green frog and the bullfrog are responsible only for the activation of ciliary movement and not for its inhibition. The cessation he regards as an autonomous inherent property of the cells. The accelerating fibers approach via the VIIth nerve and have their cells of origin in the brain. The sympathetic nerve trunk carries none of them.

That one is not entitled to translate these findings to the human subject, nor indeed to other animals and other regions is emphasized by Lucas' own findings that the nerves in the tracheas of turtles and ducks have no such influence upon the cilia as that just described by him for frogs.[27] Flatly, no one today knows what activates the cilia in the human nose.

The curious fact remains that the effective beat of the nasal cilia is always in one direction: toward the pharynx. As part of this plan, it follows that the beat within the sinus is always toward the ostium. When the membrane is injured and new epithelium is formed, the beat of the new cilia continues in the proper direction.

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26. Lucas, Alfred M.: Neurogenous Activation of Ciliated Epithelium, Am. Jour. Physiol., 112:468 (July), 1935.
27. Lucas, Alfred M., and Douglas, L. C.: Principles Underlying Ciliary Activity in the Respiratory Tract. Arch. Otolaryng., 21:285, 1935.

In tissue cultures the author has never seen cilia beating toward the source of the growth but always away from it in the direction of new cell division.

The question has been asked—but not answered—"Why in the development of a sinus away from the nasal chamber, do not the cilia on the forward edge of the ostium beat into it as they must originally have done at this point?"

No attempt is made to include here a complete list of theories, nor even a full bibliography regarding them, as they are not of great importance to the present theme, and as the great mass of experiment has been upon lower marine forms. Those especially interested are referred to Gray and Möllendorff in the works cited.

ENERGY. The amount of work which cilia perform is difficult to describe accurately, as the methods of measurement have depended largely upon the movement of foreign bodies upon their surface. This introduces variables and inaccuracies. The classical figures of Bowditch, based upon the propulsion of particles of known weight up inclined planes indicate a lifting power of 7 gram-millimeters per minute, per square centimeter.[28]

The figures obtained by Maxwell were larger than those of Bowditch, beginning at 6.805 gm.-mm. per sq. cm. and reaching at times 9 to 10 gm-mm.

Within short limits, the addition of load stimulates and increases the work done, but as the load is further increased, fatigue appears. If, at this time, the original load is replaced, the speed and vigor do not immediately return to the former

28. Bowditch, H. P.: Force of Ciliary Motion. Boston Med. and Surg. Jour., 15:157, 1876.

level, but a period of two to four minutes' rest is required to restore it.

Compared to the gross anatomical nasal parts with which the clinician is familiar, these structures, forces, speeds and distances are so insignificant that in spite of himself he underestimates them.

The author has often found it expedient in teaching, to multiply all values by 100 and to fabricate an imaginary structure which can be regarded from a more familiar and objective viewpoint. The comparisons thus obtained are truly enlightening.

The nose becomes a sort of duplex apartment or rather two apartments, mirror images of one another, with a wall—the septum—between.

On the first floor is the antrum, on the second are the ethmoid and the sphenoid cells, and under the roof, reached by a narrow stairway, is the frontal. These rooms have no doors opening into the halls—only transoms—or if you prefer, ventilators. The wallpaper in these apartments, miraculously, is self-regenerating. As it forms it slides slowly along the walls, to and through the ventilators to merge with the paper in the hall. From here it is unceremoniously thrown down the back-stairs into the incinerator. Fancy! clean carpets and wallpaper from cellar to garret every twenty minutes.

Now let us examine one of these rooms—the antrum. We will take no liberties with any of the accepted figures. Only the decimal point we will shift two places to the right.

Our 3 cm. antrum is now a ten-foot room. It is dark, for the only communication it has with the outdoors is an 8-inch ventilator, and that opens under a penthouse in the hall.

The ventilator is adequate to the situation but it would leave something to be desired were the room required for habitation, as there is no forced draught through it. There is an intermittent breeze down the hall but most of it goes by, and what else could one expect of an 8-inch ventilator under a penthouse—and no circulation?

The walls, ceiling and floors of this antrum are lined with the thinnest imaginable velvet, for the cilia even now are only 1/42 inch long and 1/300 inch thick. And yet if one were to heave a washtubful of molasses and a bucket of sand into that room, they would mop it up, carry it across the floor and discharge it through the ventilator in a short ten minutes!

May the reader forgive this grotesque comparison, but if he be a surgeon, may he likewise not forget it.

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CHAPTER XIV

CILIA—GROWTH AND REGENERATION

EARLY OCCURRENCE — REGENERATION — PROCESS OF EPITHELIZATION—REGENERATION NOT INVARIABLE—RESULTS OF IRRITATION—CILIA PERSIST WITH INFECTION—CULTURE OF MAMMALIAN CILIA IN VITRO.

EARLY OCCURRENCE. As might be expected from their antiquity, cilia appear early in the embryo. They have been observed in the four weeks' guinea pig embryo, the full period of gestation being 63 days.

In cultures from these tissues, cilia follow closely upon cell division and only the extreme borders of the new growth made up of the youngest cells are inactive.[1]

Ciliated epithelium develops in the human nasal fossa about the fourth month of fetal life and by the fifth month is general.[2]

It has been found as early as the 14th week.[3] At this time also the glands which have made their appearance in the 9th week become branched into typical tubular-acinous forms.

1. Proetz, A. W., and Pfingsten, Marian: Tissue Culture of Nasal Ciliated Epithelium. Arch. of Otolaryng., 29:252 (Feb.), 1939.
2. Schaeffer, J. Parsons: The Anatomy of the Paranasal Sinuses in Children. Arch. Otolaryng., 15:657 (Apr.), 1932.
3. Honda, T.: Entwickelungsgeschichtliche Studien über die Nebenhöhlen der Nase bei menschlichen Embryonen. Nagasaki Igakkwai Zassi, 15:1144 (July 25), 1937.

Histologische Studien über die Nebenhöhlen der Nase bei menschlichen Embryonen. Nagasaki Igakkwai, 15:1381 (Aug. 25), 1937.

Beziehungen der Nasennebenhöhlen der japanischen Embryonen mit der äusseren Nase, dem Schädel und ihrer eigenen nächsten Umgebung Nagasaki Igakkwai Zassi, 15:1397 (Aug. 25), 1937.

REGENERATION. After removal of normal mucosa from the dog's antrum, epithelial regeneration has been shown to take place. It requires about a month to become well established, and two months more to be completely regenerated. Five months after the removal the glands are well established and the mucoperiosteum in general looks almost normal.[4]

Examination of sections from the human antrum indicates that the process occurs in man in much the same fashion, but on this point there is some difference of opinion. It is generally held that the regenerated membrane, though in other respects apparently quite normal, is apt to contain fewer glands than the original one. Membrane removed surgically from the human, however, is not normal to begin with but in some stage of infection often advanced, and this may account for the failure of complete glandular regeneration in some cases.

Examination at intervals after a radical maxillary sinus operation, showed that the normal pseudostratified, ciliated columnar type of epithelium does not appear at once but that its regeneration as well as that of the glands is gradual, and requires about five months for its completion.[5]

PROCESS OF EPITHELIZATION. The epithelization may spread from the margins of small islands of mucosa which have been left behind but the more important process arises at the edges of the operative window into the nose.[6]

Disagreement as to the extent of mucosal regeneration is in some cases only a matter of terms.

4. Knowlton, C. D., and McGregor, G. W.: How and When the Mucous Membrane of the Maxillary Sinus Regenerates: An Experimental Study in the Dog. Arch. Otolaryng., 8:647 (Dec.), 1928.

5. Gorham, C. B., and Bacher, J. A.: Regeneration of Human Maxillary Antral Lining. Arch. Otolaryng., 11:763 (June), 1930.

6. Tonndorf: Beitrag zur Ausheilung der nach Luc-Caldwell operierten Kieferhöhle. Ztschr. f. Hals, Nasen-u. Ohrenh., 22:54 59, 1928.

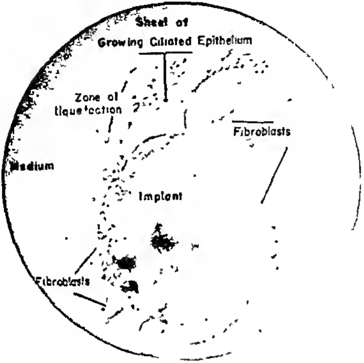

Fig. 70. Culture of ciliated epithelium.

It has been observed that if the mucoperiosteum is removed obliteration of the sinus sometimes ensues. In human sinuses the extent of obliteration depends somewhat on the size of the sinus and the condition of the bony wall. The patency of a communication with the nasal chamber is also a factor. Bone disease which may exist in the sinus wall is not necessarily uniform, therefore the type of regeneration may not be the same

in all parts of the sinus. Lapses in the mucoperiosteum may be replaced by granulations.[7]

Remnants of the mucosa left accidentally, or in the hope that they may act as islands for regeneration, sometimes merely degenerate into scar tissue or they may give rise to cysts.

Boling, working with healthy lambs, described the process by which regeneration of normal ciliated epithelium occurred after excision of parts of it. This took place from the borders of the injured area, arising from the dedifferentiated epithelium and covering the denuded surface by migration, undergoing stratification and redifferentiation.

The tunica propria was repaired by invasion of connective tissue elements into the clot. The vascular supply within the scar was somewhat less than normal. The glands also did not reach their normal degree of differentiation or number within two months.

Changes in ventilation which may bring about metaplastic alterations in the epithelium of the nose as a whole, have little effect on the healing process. Regeneration may occur even after repeated injury, without much deviation from the normal.[8]

It was Hilding's experience that if the scalp was sutured over the normal frontal sinus of a dog from which the mucous membrane had been stripped, the sinus was usually filled with scar tissue which obliterated the cavity. Sometimes a

7. Glatt, M. A: Postoperative Repair of the Paranasal Sinuses. Arch. of Otolaryng., 27:323, 1938.
8. Boling, LeRoy, R.: Regenerations of the Nasal Mucosa. Arch. Otolaryng., 22:689-724 (Dec.), 1935.

Fig. 71. Culture of ciliated epithelium. The implant, upper left. The roughly circular outline is the zone of liquefaction. The rod-like outgrowths extending down and to the right are attached above to the implant, and below to clumps of detached cells, and are being stretched by the receding of the gelatinous wall as liquefaction progresses.

small cavity persisted which in exceptional cases again became lined with ciliated epithelium, but which was usually covered with thick, white connective tissue over which the epithelium apparently could not grow. When portions of epithelium were left in the sinus, cysts filled with mucin formed within the obliterating scar.[9]

9. Hilding, Anderson: Experimental Surgery of the Nose and Sinuses. III. Arch. of Otolaryng., 17:760 (June), 1933.

Regeneration Not Invariable. He agrees[10] with Semenov and Kistner[11] that regeneration of ciliated epithelium may or may not occur following removal. He feels that it is the exceptional case in which restitution occurs and describes an experiment in which the sinus was denuded of the mucous membrane except for three islands in which the membrane was inaccessible due to pits in the bone. At autopsy four weeks later the pits were lined by good epithelium, and the spaces between with white scar tissue devoid of epithelium. To be sure, the period of observation here was not as long as that of Knowlton and McGregor.

Regeneration of the epithelium apparently occurs from the irregularly cuboidal undifferentiated basal cells, which are not destroyed unless environmental conditions are extremely severe. Latta and Schall believe these cells possess the potentialities for forming either ciliated or goblet cells, depending upon the environmental requirements while they are in the stage of differentiating.

Results of Irritation. Under conditions of acute irritation the epithelium in the sinuses becomes thicker, the cells more closely packed and the superficial cells actually more heavily ciliated.[12]

True stratified columnar epithelium gradually appears as the irritation continues. It is always associated with an infiltra-

10. Hilding, A.. Experimental Surgery of the Nose and Sinuses. III. Arch. Otolaryng., 17:321 (Mar.), 1933.

11. Semenov, Herman and Kistner, F. B.: Repair in the Paranasal Sinuses of Man Following Removal of the Mucous Membrane Lining. Proc. Soc. Exper. Biol. and Med., 27:322 (Jan.), 1930.

12. Latta, John S., and Schall, R. F.: The Histology of the Paranasal Sinuses Under Various Conditions. Annals of Otol., Rhin, and Laryng., 43:945 (Dec.), 1934.

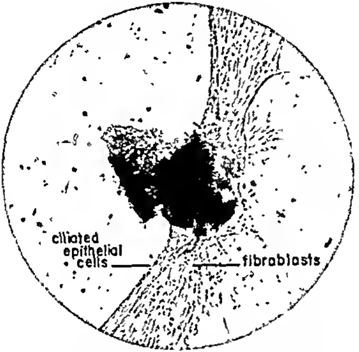

Fig. 72. Culture of ciliated epithelium. Epithelial cells spreading from implant along the surface of the medium. Zone of liquefaction on the left.

tion of macrophages, polymorphonuclear leucocytes and lymphocytes in the underlying connective tissue.

It is only after considerable hyperplasia occurs in the epithelial layers that goblet cells appear in numbers.

Matwejew's[13] view that thermo-cautery and acid escarotics invariably prevent the regeneration of the mucosa is not gen-

13. Matwejew, D. N.: Das Regenerationsvermögen der Nasenschleimhaut nach operativen Eingriffen. Monatschr. f. Ohrenh., 63:1293, 1929.

erally accepted but there is abundant evidence that this is often the case. He observes also that turbinectomy produces a narrow scar between the raw edges of the wound to both sides of which normal mucous membrane persists.

It has occasionally been stated that regeneration of the mucosa of the nose and nasopharynx may occur even after atrophic rhinitis. This is extremely doubtful except in the case of young children in whom the atrophy was secondary to some other disease process.[14]

As shown by these accounts the influences which determine the growth and regeneration of the nasal epithelium are not fully understood, but the facts seem to demand attention: (1) that after complete removal the mucosa of a sinus can be regenerated with normally functioning ciliated columnar epithelium; (2) that in clinical practice this regeneration is not invariable; and (3) that normal vigorous ciliary activity usually—in fact, almost invariably—exists within a sinus, even in the presence of overwhelming infection of long standing.[15]

CILIA PERSIST WITH INFECTION. To account for the last, there are two possible explanations: either the infection in its acute stage destroys the epithelium, which is later regenerated in spite of the persistence of the infection in the deeper layers of the mucosa, or the organisms penetrate to the deeper layers only at scattered points, invading the tunica propria and leaving the greater part of the epithelium intact. There is evidence to be had, from fixed and stained sections of tissue, in support of both views.

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14. Putschkowskaja, N. A.: Über die Regeneration der Nasenrachenschleimhaut nach atrophischen Prozessen. Acta Otolaryng., 30:243 1934.
15. Proetz, A. W.: Studies of Nasal Cilia in the Living Mammal. Ann. of Otol., Rhin. and Laryng., 42:778 (Sept.), 1933.

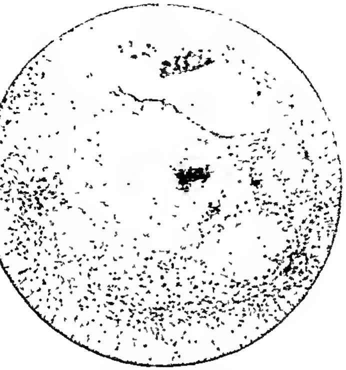

FIG 73. Culture of ciliated epithelium. Looking down on the surface of the implant which is covered with cilia. Growth in several locations, to right, above and below. Fibroblasts growing at the periphery.

CULTURE OF MAMMALIAN CILIA IN VITRO. In 1936 the author and one of his associates[16] undertook to grow mammalian ciliated epithelium in cultures in the hope of discovering in the behavior of the living tissue something which might be clinically useful in fortifying the epithelium in the nose and in expediting its repair once it has been injured.

16. Proetz, A. W., and Pfingsten, M.: Ciliated Nasal Epithelium: Its Culture in Vitro: Preliminary Report. Ann. Otol., Rhin. & Laryng., 45:400 (June), 1936.

Literature relative to the problem is almost nonexistent; although experiments with other epithelia abound, they are not sufficiently closely related to be pertinent. The epidermis of the frog has been grown.[17] Strelin[18] reported a culture of bronchial epithelium from a rabbit, but the period of growth was short (nine days), and the author's conclusions therefore seem incomplete. Carleton,[19] working with late fetal cat and rabbit bronchi, was unable to maintain ciliary growth in vitro. Vogelaar noted growth of epithelium in cultures of material from the human thyroid gland. There was no mention anywhere of an attempt to grow nasal cilia, hence nothing to suggest the proper medium for their proliferation.

Since the main purpose of the study was to obtain some knowledge of growth-controlling factors which might subsequently be applied clinically, it seemed important to resort, for both media and feeding solutions, to substances of known composition.

In this respect, the medium devised by Vogelaar and Erlichman,[20] seemed especially suitable; moreover, one type of mammalian epithelial tissue had already been made to grow on it.

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17. Uhlenhuth, E.: The Form of the Epithelial Cells in Cultures of Frog Skin and Its Relation to the Consistency of the Medium. J. Exper. Med., 22:76, 1915.

18. Strelin, G. S.: Ueber *in-vitro Kulturen* der Bronchen des Kaninchens mit besonderer Berucksichtigung des Epithels Arch. f. exper. Zellforsch., 9:297 (April 8), 1930.

19. Carleton, H. M.: Growth, Phagocytosis and Other Phenomena in Tissue Cultures of the Foetal and Adult Lung. Phil. Tr. Roy. Soc., London, s B 213:365, 1925. Chlopkow, A. M.: Intestinal Epithelium of Adult Rabbit Cultures in Vitro. Arch. f. exper. Zellforsch., 10:299 (Feb. 16), 1931.

20 Vogelaar, J. P M., and Erlichman, E.: A Feeding Solution for Cultures of Human Fibroblasts, Am. J. Cancer, 18:28 (May), 1933; The Growth of Human Fibroblasts in Media Containing Silver, ibid., 22:555 (Nov), 1934; Some Remarks on the Growth of Human Fibroblasts in Media Containing Copper, ibid., 22:66 (Sept.), 1934.

Fig. 74. Culture of ciliated epithelium. The black line is the margin of the zone of liquefaction. As it recedes downward and to the left it draws a rod of new epithelium after it.

From the beginning some growth was obtained in this medium.

However, certain minor modifications were required before it was adequate for the purposes of the experiment. At first only thin strands of epithelial cells could be grown, which, while covered with active cilia, were too fragile for study. Later, by modifying the medium somewhat, it became possible to grow epithelial cells in sheets and to observe something of the character of their growth and proliferation.

The tissue used in these experiments was the mucosa of the turbinates and the septum of guinea pig fetuses at term, in order to avoid the bacterial contamination which occurs as soon as the animal breathes. This is no longer embryonic tissue, as the period of gestation has been completed.

Through a small incision in the uterine wall the embryos were removed, the umbilical cord cut, and each animal placed in a sterile container with a small amount of Locke solution.

Plasma from the mother was used in the medium which contained also calcium- and magnesium-Ringer solutions, peptone, thyroxin, hemin, cysteine hydrochloride, dextrose, insulin, and the acid phosphates of sodium and potassium.

In each case the implant was a fragment of epithelium removed from the nose, usually a turbinated body, with a small mass of fibroblasts adhering to its under side.

The following observations were made:

There is a tendency for the edges of the epithelium to curl under, and sometimes around the fibroblasts. When this occurs and there is no free edge, the epithelium does not grow.

Growth may be apparent as early as the second day but usually begins on the third or fourth day. After an incubation period of a few hours, migrating cells often emerge from the fragment and may surround it in a rather dense zone.

Whether growth is apparent or not liquefaction of the medium where it is in contact with the epithelium begins practically at once. Fibroblasts grow out from the implant in radiating strands and penetrate the medium for some distance and for some time (two to three days) before liquefaction takes place.

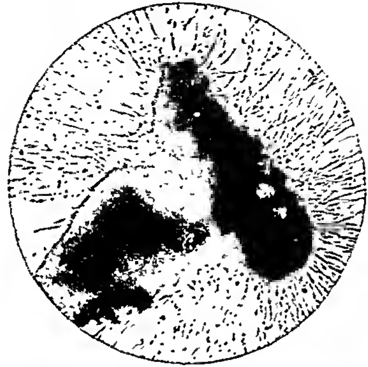

Fig. 75. Culture of ciliated epithelium. The implants have curled up, with the cilia inside. Fibroblasts are growing from all surfaces.

The amount of liquefaction appears to be increased when the growth is rapid. The new cells may live for some time in the liquefied medium but do not multiply and eventually die unless the medium is changed.

When the epithelium grows in thin strands, and to a lesser degree when it grows in sheets, the distal cells cling to the recedings wall of the medium (receding because of liquefaction) or to any debris which may be there. The epithelium spreads

also along the surface of this wall in a sheet. When the wall recedes faster than the tissue grows, the strand of cells is broken. With the firmer, more slowly liquefying medium this does not occur.

In cultures, many of which were cultivated from three to four weeks, there was never any difficulty in distinguishing the epithelial cells from the fibroblasts. The author agrees with Ebeling and Fischer[21] that when epithelial cells and fibroblasts are growing together in the same medium they both maintain their individual characteristics. The epithelium, whether growing in tubular formation or as a sheetlike membrane, always tends to grow more compactly, with the individual cells adherent to one another. The typical network of the fibroblasts is always evident. Membrane-like or sheet-like growth of the epithelium is rapid, more so than tubular growth. We have not seen the dedifferentiation described as occurring in related tissues. The growth and migration of epithelial cells seem to be more dependent on the mechanical conditions of the clot than are those of the fibroblasts.

Local changes in surface tension of the medium may account for many of the varying patterns of growth.

Ciliary motility can frequently be seen on individual epithelial cells, which have wandered or possibly have regenerated from a small clump of cells far removed from the original fragment. The vitality of these isolated cells is great. Often they assume a spherical form and are covered on all sides by

21. Ebeling, A., and Fischer, A.: Mixed Cultures of Pure Strains of Fibroblasts and Epithelial Cells, J. Exper. Med., 36:285 (Sept.), 1922. Fischer, A.: Tissue Culture: Studies in Experimental Morphology and General Physiology of Tissue Cells in Vitro, in Contributions from the University Institute for General Pathology, Copenhagen, Levin & Munksgaard, 4:99, 1926.

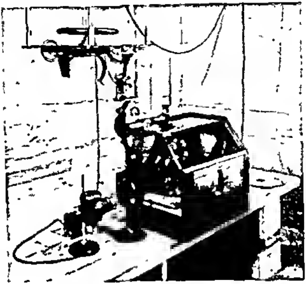

Fig 76. Apparatus for making time-lapse cinemicrographs of tissue cultures. The microscope stands in an incubator on a vibration-free table. The camera is not in contact with it. Mechanically, the light is switched on, the exposure made and the light switched off. The interval between exposures determines the degree of apparent acceleration in the picture.

cilia. Sometimes they are caught in the meshwork of fibroblasts.

The epithelial cells usually develop a yellow cast. Mitochondria in individual cells are often visible in the cytoplasm in the form of fine rodlike structures. The epithelial cells usually contain a large number of minute refractile granules.

The promptness with which ciliary activity appears on the surfaces of new cells is amazing. Approximately four-fifths of the sheet of new cells is in active motion in all the specimens.

The actual time of the appearance of activity varies with the rapidity of growth of tissue.

It has been observed also that ciliary activity comparable to that in the adult is found in the guinea pig as early as at one-third term, or after about three and one-half to four weeks of a sixty-three day gestation.

Carleton[22] has stated that in cultures which he made of the larger bronchi in later periods of fetal life (cat and rabbit) when cilia were present they disappeared in vitro. He reported that the farther the cells grew from the parent epithelium the less they resembled it. The author's observations are not in accord with this, as in his cultures, the new epithelial cells were invariably covered with active cilia, whose motion and speed of vibration could not be distinguished from those of the parent cells.

With time-lapse photography (acceleration 960X) definite characteristics of growth may be observed. The epithelial cells appear to stretch in the direction of growth of the general mass and then to contract again to their previous shape and position. They do this a number of times before the cells divide. Growth proceeds along what appear to be extremely slender protoplasmic threads, first sent out by the cell in the direction of growth.

Wandering cells, which progress relatively rapidly by means of ameboid movements, abound wherever growth is taking place. They were not seen to divide. They are especially active and abundant in regions where there is a dense growth of fibroblasts.

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22. Carleton, H. M.: Growth. Phagocytosis and Other Phenomena in Tissue Cultures of the Foetal and Adult Lung. Phil. Tr. Roy. Soc. London, s. B. 213:365, 1925.

The motion pictures reveal that these cells are constantly dynamic. Cells which appear to be at rest when observed microscopically are actually busy—now pulling, now twisting, now sending out processes in which streams of granular material can be seen. Mitosis indicates pronounced activity, but even when mitosis is not in process every structure may be said to be active. The wandering cells are particularly vigorous.

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Semenov, H., and Kistner, F. B.: Repair in the Paranasal Sinuses of Man Following Removal of the Mucous Membrane Lining. Proc. Soc. Exper. Biol. & Med., 27:322 (Jan.), 1930.

CHAPTER XV

CILIA—PHYSICAL AND CHEMICAL EFFECTS

DRYING—LOCAL DRYING—THERMAL EFFECTS—FRICTION — IRRADIATION — HYDROGEN ION CONCENTRATION — ACTION OF DRUGS — SODIUM CHLORID—DISTILLED WATER—LIQUID PETROLATUM—EPHEDRINE SULPHATE — AMPHETAMINE — EPINEPHRIN — COCAIN HYDROCHLORID — CAMPHOR — MENTHOL — THYMOL —MILD SILVER PROTEIN—SILVER NITRATE—DIBROM-OXYMERCURI-FLUORESCEIN — SODIUM ETHYLMERCURI-THIOSALICYLATE — ALCOHOL — SEDATIVES — ETHER —CHLOROFORM—NITROUS OXIDE—WETTING AGENTS—INORGANIC CHLORIDS—ALIZARIN—OXALATES.

DRYING. The only natural enemy known to cilia in their line of function is excessive drying. They are entirely dependent upon a coating of moisture for their activity and for their preservation. The drying need continue for only a few minutes to destroy them. After that time a fresh supply of fluid does not resuscitate them.

When an animal's sinuses are opened for observation, artificial moistening must be instituted practically at once, as the number of mucous glands in the sinus is only sufficient to maintain the moisture where no air currents exist. When the respiratory stream is allowed to course through the open sinus it dries promptly and the cilia succumb.

The immediate neighborhood of the ostium, which bears the impact of the minute quantity of fresh air entering a sinus

during respiration is much better supplied with glands than the remainder.

Excessive drying, sufficient to destroy cilia, occurs in the nose under four circumstances: (1) through some disability of the mucous glands, which may be part of a general systemic dyscrasia (this, in comparison to the other three, is extremely rare); (2) through the uneven distribution of air, resulting from some deformity or obstruction, following which jets of dry, inspired air may be projected against certain areas in the nose in quantities in excess of the membrane's ability to moisten them; (3) through a similar condition following the surgical removal of important structures; and (4) through continued excessive dryness of inspired air, the result of improper heating of dwellings or of natural climatic aridity.

The causes in the first case lie without our province.

The second case is usually the result of a deviated septum. The condition may not be perceptible at first glance, because the air currents from the two nostrils may be well-balanced in volume. On the side of the deformity, however, especially if this is of the plow-share type, the stream of inspired air is diverted from its normal course and projected upward either against the face of the sphenoid or the region of the spheno-palatine ganglion, or it may be turned laterally against one or both lips of the eustachian tube.

Polyps, hyperplasias, foreign bodies or any other obstruction may have the same effect through restricting the breathing channel. The jet of air in this case may be projected in any location or direction, depending upon the position of the obstruction.

In the third case, that resulting from operative procedures, the dry spot is usually found within one of the posterior sinuses. If masses of tissue, turbinated bones and the faces of sinuses are removed in such a way as to project the inspired air against the mucosa of the remaining sides, which is physiologically unable to cope with this excessive ventilation, drying, destruction of cilia and finally, metaplasia of tissue result. In this condition, the sinus is unable to cleanse itself.

LOCAL DRYING. The author has watched the effect of local drying by projecting a jet of dry air onto the mucosa through a capillary tube. These experiments were done in the summer with the room temperature closely approximating body temperature and any cooling effect was confined practically to that of evaporation.

A small area under observation was dried and the cilia in this area ceased beating. A fringe of activity persisted so long as sufficient moisture remained. The circle of inactivity enlarged as the dry spot grew wider. If this was allowed to continue for several minutes, the action could not be re-established by moistening. Flushing with physiologic sodium chlorid solution or Ringer's solution, after a short time, however, restored the cilia and the same cycle recurred.

The fourth case, excessive drying due to artificial heating, is exceedingly common in American homes and persists as long as the furnaces are in operation. The cold outside air of winter carries very little moisture. When this is brought indoors and heated, the relative humidity drops to a very low point unless the required moisture is artificially supplied, and evaporation from moist bodies is very rapid. Doors shrink, furniture cracks, plants wilt and the respiratory mucosa dries with resulting discomfort, burning, headache and cough. (See p. 163.)

THERMAL EFFECTS. Cytologists have described accurately the alterations in speed and effectiveness of ciliary action in mollusks and amphibians concomitant with thermal variations.[1] These activities can be thermally controlled, and the reactions are reversible, within limits.

By means of an apparatus constructed for the study of cilia in the sinus of the living rabbit[2] temperature determinations were made on freshly removed human mucosa and checked against similar ones made on living rabbits. The results were recorded in cinematographs made at various speeds.

The frequency of beat was greatest between 18° and 33° C. and varied from seven to ten or more per second. Controls were maintained at room temperature, which ranged from 25 to 30 C. All the experiments were begun with the membrane at 30 C. The temperature was then reduced very slowly and the speed of the cilia noted. At 18 C. there occurred a slight diminution of rate, which progressed with reduction of temperature until all motion ceased in various specimens between 7 and 12 C., the lower temperatures predominating in the sinuses of the living rabbit. Owing to the heat supplied by the animal itself and to the difficulty of observing the cilia while keeping the area at a low temperature, this lower figure is only approximate.

When the temperature was gradually elevated, motion was resumed, and by the time the thermometer registered 18 C. it was extremely rapid—much more rapid than at the beginning of the experiment, reaching 15 or more beats per second. This frequency gradually receded to normal as the tempera-

1. Gray, J: Ciliary Movement. Macmillan, N. Y., 1928.
2. Proetz, A. W.: Studies of Nasal Cilia in the Living Mammal. Ann. Otol., Rhin. & Laryng., 42:778 (Sept.), 1933.

ture continued to rise. The acceleration at 18 C. did not take place during the gradual lowering of the temperature, nor did it continue for more than a minute when the temperature was held for a time at that point.

At 35 C. it became necessary to supply fluids with increasing frequency, owing to evaporation. At 40 C. motion was greatly retarded, and at 43 to 44 C. it ceased entirely. Some groups of cilia succumbed before others, so that before ceasing the motion became irregular.

On cooling the membrane once more, the cilia remained inactive and motion was not resumed even after several hours at 30 C. Coagulation had occurred and the cilia were permanently injured.

It is curious that these figures correspond fairly closely to those recorded by Gray[3] for *mytilus*, and for the esophagus of the frog. The relation becomes more reasonable, however, in the light of Gray's observation that the responses noted by him are characteristic of muscular responses as well. This obtains throughout the scale, including the so-called heat rigor at the higher temperatures, following which the tissue is no longer reactive.

The practical inference is that the respiration of cold air does not damage the cilia, especially in view of the fact that inspired cold blasts are constantly alternated with expired blasts at 37° C.

The author's determinations of temperature effects were made on freshly removed human mucosa and checked against similar ones on living rabbits. The results were recorded in cinematographs made at normal speeds.

3. Gray, J.: Ciliary Movement. Macmillan, N. Y., 1928.

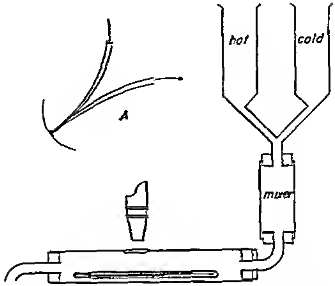

Fig. 77. Diagram of the apparatus for studying the effects of temperature upon the cilia. Strips of tissue are laid upon the glass tube with the thermometer, under the microscope. In the sinus the tubes shown at A are used to carry solutions of a known temperature to and from the part.

The apparatus[4] consisted of a glass tube 12 cm. in length, through which water was allowed to flow, a thermometer in the tube recording its temperature. This tube was fastened on the stage of a microscope, and the specimen of mucosa spread on it was examined by reflected light. The objective used was 6.5X; the ocular, 16X; hence a magnification of approximately 104 diameters was obtained on the film.

The water was conducted to the tube, through a mixer, from two containers, one heated and the other iced. Accurate

4. Proetz, A. W.: Effect of Temperature on Nasal Cilia. Arch. of Otolaryng., 19:607 (May), 1934.

temperatures from 5 to 50° C. could thus be produced and maintained.

Corrections were made for small amounts of heat from the illuminant. These were determined with a thermocouple and after three minutes were found to be 1° C. for the small incandescent bulb used for ordinary examination. Correction for the arc lamp used in photography was 3.1° C., also after three minutes. All the exposures for examination were restricted to that length of time. When it became necessary to supply moisture to the membrane in the form of Ringer's solution, sufficient time was allowed to elapse for equalization of temperature.

For the determinations on the living rabbit the double capillary tube was employed, to supply and to remove the Ringer's solution maintained in a constant flow at the desired temperatures. The fluid passed over the recording thermometer 5 cm. from the contact point, reducing the error to an acceptable minimum.

FRICTION. Surface friction is injurious to cilia and when it continues over a period of time as it does in industrial situations or through nasal polypi, metaplasia of the tissue ensues, resulting in a stratified squamous non-ciliated epithelium.[5]

IRRADIATION. Observers differ as to the effect of irradiation upon ciliated epithelium. Heine applied it in three ways: *first*, the exposure of hanging drop sections of ciliated epithelium to the action of radon seeds; second, the exposure of sections of rabbit's trachea to the direct action of roentgen rays; and third, the implantation of radium into the nostrils of rabbits.

5. Freedman, A. O.: The Pathogenesis of Polyposis Nasi. Arch. Otolaryng., *2:250, 1925.*

He writes:[6] "Shortly after the placing of 6 mc. seeds about the tissue ciliary motion increased. Thereafter it seemed that an increase in ciliary activity was evident with the placing of every dose. [What form this increase in activity took, whether in speed or in vigor, is not stated.] With constant exposure to 6 mc. the tissue lived ninety-six hours. The control lived eight days. Nothing startling was observed . . .

"Ciliated epithelium is not a delicate structure. If one considers that a single dose of unfiltered roentgen ray of eight erythemas is the maximum for the skin of man, the picture of the severity of a burn produced by a single dose three times that amount, or twenty-four erythemas, is almost beyond one's imagination. However, the evidence points toward the fact that these frail appearing cells do stand such a dosage with impunity."

Not only were these cells unaffected but the rate of ciliary beat was unaltered.

Fenton and Larsell[7] recovered practically normal epithelium, at the time of a radical maxillary sinus operation, from a man of 36 who had previously received several courses of deep roentgen ray therapy over a period of five months. The tunica propria, however, was excessively thickened and fibrotic with practically no infiltrating cells. A cyst wall from this case was also highly fibrotic but the epithelium was normal.

Frenckner's[8] reports are at variance with the foregoing.

6. Heine, Lyman H.: The Effect of Radiation Upon Ciliated Epithelium. Ann. Otol., Rhin. & Laryng., 45-60 (Mar.), 1936.
7. Fenton, Ralph A., and Larsell, Olof: Experimental and Clinical Sinusitis. Trans. Amer. Acad. Ophthal. and Otolaryng., 1935.
8. Frenckner, P.: The Effect of Roentgen and Radium Radiation Upon the Action of Cilia. Acta. Oto-laryng., 27: first part, 297, second part, 397, 1939.

Hydrogen Ion Concentration. The action of ions on ciliary movement has occupied observers since Lillie[9] in 1906 published a paper on the relation of ions to contractile processes.

He showed in *mytilus* that the inhibition of ciliary movement appears to depend upon a swelling effect produced by certain cations which, if it continues, brings about the disintegration of the cell. The effect can be neutralized by the addition of a little acid (such as hydrochloric) containing hydrogen ions.

The figures given by most biologists in regard to the pH are based upon *mytilus* which lives in sea water and they are not therefore directly applicable to mammalian cilia.

According to Mittermaier[10] the pH of the secretions in chronic sinus suppurations tends to approach the acid side. Buhrmester[11] records the average pH of normal human secretion to be 7.56, whereas that of pus found in 15 suppurative cases averaged only 6.48. Commenting upon this paper, Negus,[12] who himself has contributed to the subject, writes, "In view of results found by experiment, these figures are most interesting. The experimental figure of 6.4 which causes paralysis of cilia corresponds closely to the pH found in cases in which ciliary action is presumably in temporary abeyance. I believe that Mr. Tweedie . . . has obtained figures of a different character.

9. Lillie, R. S.: The Relation of Ions to Contractile Processes. Amer. J. of Physiol., 17, 1906-7.

10. Mittermaier, R.: Hydrogen-ion Concentration in Chronic Sinus Suppuration. Zeitschr. f. Laryng. Rhin. Otol., Vol. 19 (July), 1930; also Archiv. f. Ohren- Nasen-u. Kehlkopfhlk. 1930.

11. Buhrmester, Catherine C.: A Study of the Hydrogen-ion Concentration, Nitrogen Content, and Viscosity of the Nasal Secretion. Ann. of Otol., Rhin. & Laryng., 42:1041 (Dec.), 1933.

12. Negus, V. E.: The Action of Cilia and the Effect of Drugs on Their Activity. J. Laryng. and Otol., 49:571 (Sept.), 1934.

"On the existing evidence, it appears that in some cases of suppurative sinusitis ciliary action is paralysed by the altered reaction of the inflammatory exudate. A similar condition may be inferred in some affections of the tracheo-bronchial tree. Paralysis of the most important means of protection leads to multiplication of organisms with subsequent changes in the mucous membrane.

"Proetz has examined the epithelium removed from the maxillary sinus of many patients suffering from suppurative inflammation of long standing, and he has found the cilia active in practically every case. This clinical observation would, of course, upset the result of any laboratory experiments.

"The explanation may be found in observations made by Mittermaier. He found that the pH of the tissues does not of necessity correspond with that of the secretions. The tissues are flooded with blood, and their reaction approaches the normal figure found in blood."

Chronic nasal infection does not of itself preclude ciliary activity. It is the rule that even in the presence of copious pus areas of normal activity persist.

Action of Drugs. Reports of the effects of drugs upon ciliary activity are numerous. In 1934, Lierle and Moore[13] made a series of observations, employing an apparatus similar to one employed by Lucas in his work on *Modiolus demissus*. Human tissue obtained from the operating room was used for the greater part of these experiments but some of them were on the mucosa from a dog's naso-pharynx.

13. Lierle, D. M., and Moore, P. M.: Effects of Drugs on Ciliary Activity of Mucosa of Upper Respiratory Tract. Arch. Otolaryng., 19:55 (Jan.), 1934.

The author's series of experiments,[14] made about the same time, were arranged in three parallel series, for the sake of comparison and accuracy; the first upon the living rabbit membrane undisturbed in the sinus; the second upon the human material removed from sinuses at operation and kept in physiologic sodium chlorid solution or in Ringer's solution; the third, upon extirpated rabbit membrane kept and examined in the same manner as the human material. It is felt that if the effects in these three series coincide deductions from them may reasonably be applied to living human membranes.

It was considered important to make at least part of these observations upon the undisturbed living mucosa, not only because of the circulation in the membrane, but chiefly because of the continued presence of the mucous blanket. In the excised specimens this is soon washed away and is, of course, not replaced. This applies equally to the killed animal. In the living animal the flow of mucus continues—is, in fact, sometimes stimulated, which may mitigate the effect of the drug, but sometimes increases it.

Each observation was made upon a piece of fresh tissue not previously subjected to any other drug. Some observers have subjected a single strip of tissue to a succession of drugs, not only when the previous drugs have produced no apparent effect but even when "the activity of the cilia was below par before the [drug] was applied because of poor recovery from the previous application of a drug."

To the apparatus, which included a microscope and a motion picture camera for recording ciliary activity and other

14. Proetz, Arthur: *The Effects of Certain Drugs Upon Living Nasal Ciliated Epithelium.* Ann. Otol., Rhin. & Laryng., 43:450-463 (June), 1934.

mucosal functions such as the capillary circulation, was adapted the double capillary tube described on page 214.

Previous experiments having shown that the cilia were more active at 30° C. and below than at 37° C., and that low temperatures did not incapacitate them, no precautions were taken to keep the specimens warm. At operation the tissue was transferred directly from the patient to Ringer's solution (in a few cases Tyrode's) at room temperature. Portions not used for study remained in these solutions as controls. When it was necessary to preserve them overnight, they were left in a refrigerator (circa 5°C) and examined the following day at room temperature. Under these conditions the cilia remained active through the second, and at times even the third day.

The plan followed in the rabbit experiments was essentially that described for the recording of ciliary activity (p. 213). A cooling chamber was introduced between the condensing lens of the vertical illuminator and the source of illumination, and the light was shut off between observations to avoid heating.

Two types of application were made:

First, the drug was allowed to act upon the surface for a short time in order to simulate clinical conditions. After removal, in the living rabbit, nothing further was done, the circulation and secretion being depended upon to free the membrane of the drug. The extirpated specimens were washed with Ringer's solution from beakers containing the controls in order to maintain similar conditions.

Second, the drug was continuously applied (the extirpated specimens being immersed in it) until motion ceased.

Sodium Chlorid Solutions. Cilia of both man and rabbit remain active for long periods in .9% sodium chlorid at room temperatures between 25° C. and 30° C. Some of the controls were beating vigorously at the end of six hours.

As the sodium chlorid solution is increasingly concentrated, areas of cilia cease beating. The effect is unlike that of cold, under which a general slowing occurs. At a concentration of 4% to 4.5% all activity ceases.

If the membrane is washed within a few minutes with distilled water and again immersed in .9% sodium chlorid solution, activity soon returns which appears in nowise different from that of the controls.

If the concentration of the solution is reduced, the sharp outlines of the cilia are gradually lost and the surface becomes cloudy. Even groups of cilia can no longer be distinguished, and all motion ceases at .2% to .3% concentration. Addition of sodium chlorid in any concentration now fails to restore motion. The cilia have been permanently disabled.

Distilled water naturally has the same effect as these dilute sodium chlorid solutions.

Stark[15] irrigated the nasal fossae of rabbits with .9% sodium chlorid solution at 40°. From three to twenty-four irrigations were made daily. Under these trying conditions, 75% of the rabbits were found to have mucopurulent secretions in the nasal fossae and in the paranasal sinuses. This can scarcely be regarded as a representative clinical test.

15. Stark, W. B.: Irrigations with Aqueous Solution: Their Effect on the Membranes of the Upper Respiratory Tract of the Rabbit. Arch. Otolaryng., 8:47 (July), 1928.

Liquid Petrolatum (Light. Sp. Gr. .880). Cilia act indefinitely when the specimen is immersed in this medium or when the living sinus is flooded with it. One has the impression that streaming, however, is feeble or absent. Stray erythrocytes on the surface show no tendency to move along as they so definitely do in mucus. If, after 20 minutes' immersion in this oil, the surface is bathed in 10% cocain hydrochlorid solution, action ceases instantly, suggesting that the oil was not in actual contact with the cilia at all, but separated from it by mucus.

There are several factors which render it impossible to make accurate time observations of the effects of oily solutions upon the mucus covered membrane.

First, when oil is applied to the wet mucosa it flows over the entire surface and later breaks into globules of various sizes which distribute themselves upon the face of the specimen. The distribution is unequal and various fields are affected in different degrees.

Second, if the entire specimen is immersed in the oil, there remains an envelope of watery solution about it for a variable time. The oil does not "wet" the membrane.

Third, the optical system has been adjusted for observing the cilia in a watery medium. In order to do this, the angle of incidence of the illumination is adjusted so that the light is reflected back into the objective. When now the oily solution is introduced between the object and the objective, light is reflected not only from the oil surface, which can be avoided by the use of an immersion cone, but from the interface between the oily and mucous coats, which cannot. Under these conditions, the cilia cannot be seen and the observation must be interrupted until the oil flows away sufficiently to restore

the optical system to its previous status. It is at some time during this interval that the effect of the oily solution upon the cilia is produced. For this reason, the effect can be recorded in minutes, only approximately.

Fox[16] as early as 1930 wrote that liquid petrolatum sprayed into the nose causes dire results in the lung, a fact much emphasized by others in recent years. In reporting the effects of camphor, menthol and eucalyptol on the nasal mucosa, Fox makes the following comment upon the controls: "Four of the animals sprayed with liquid petrolatum died from 'snuffles' before the fifth week . . . At autopsy, however, the nose and sinuses were even less involved than those of the group treated with camphor. In only one animal was pus found in the sinuses. Two of these animals had minute abscesses in the lungs." Similar changes were encountered in rabbits sprayed with 5% eucalyptol and 5% camphor.

Cannon[17] has lately epitomized current opinion on the use of oils in the respiratory tract, in a brief review.

Ephedrine Sulphate. Three per cent in physiological sodium chlorid solution. Extirpated membranes showed ciliary activity for 15 minutes or more after immersion in 3% ephedrine solutions. After returning to Ringer's solution, some areas resumed normal activity. The living mucosa in the rabbit seems unaffected by this solution.

Two per cent in physiological sodium chlorid solution. Five minute applications of this concentration followed by Ringer's solution produced no demonstrable changes. Continuous im-

16. Fox, Noah: Effect of Camphor, Eucalyptol and Menthol on the Nasal Mucosa. Arch. Otolaryng., 11:48 (Jan.), 1930.
17. Cannon, P. R.: The Problem of Lipoid Pneumonia. J. A. M. A., 115:2176 (Dec. 21), 1940.

mersion for as long as two hours sometimes failed to stop activity. Neo-synephrin 1/4% resembled this in every way.

One-half per cent in physiological sodium chlorid solution. In the rabbit, and in human specimens, activity in this solution, which is recommended for treatment by displacement, differed in no way from the controls.

Ephedrine 1% in oil averaged 19 minutes.

Fox[18] reports that ephedrine in dilutions of 1:50, presumably in distilled water, when sprayed daily over the mucous membranes of rabbits for three months, caused no appreciable injury to the tissues.

Amphetamine (Benzedrine, A-Methylphenethylamine). An inhaler was attached through adaptors and rubber tubing to one arm of the capillary tube. The control current of air was first passed through the adjacent tube for 2 minutes to make sure that the drying effect was not sufficient to stop the cilia. At the end of this time, the air was allowed to flow through the inhaler, projecting its fumes against the membrane. This stream of vapor was interrupted only occasionally for the purpose of moistening with Locke's solution as required by the drying of the surface of the control area. There was no appreciable change in the amplitude or rapidity of the ciliary beat at the end of 20 minutes, when the experiments were terminated. This was true in every case, whether the membrane was excised or *in situ*.

The pure drug applied to the mucosal surface stopped all ciliary motion instantly.

18. Fox, Noah: Chronic Effect of Epinephrine and Ephedrine on Nasal Mucosa. Arch. Otolaryng., 13:73 (Jan.), 1931.

One per cent solution in liquid petrolatum caused slowing in a variable number of minutes, beginning in from 3 to 7 minutes and persisting over the period of the experiment.

Two per cent solution in liquid petrolatum caused appreciable slowing within a few minutes after application, which occurred in varying degrees over the field, some areas being less affected than others but all areas slowing to 3 to 6 beats per second.

Three per cent solution in liquid petrolatum caused a general slowing and cessation in from 3 to 6 minutes, very few areas being active at the end of that time.

Epinephrin 1:1000 caused immediate cessation of beat, which in the large majority of instances could not be re-established. In one case, motion having stopped in a few seconds, application of Ringer's solution for 45 seconds succeeded in restoring it, after which it continued for 1 hour and 30 minutes. The control in this case beat for 6 hours. In the rabbit, 10 seconds sufficed to stop action, which could not be resuscitated.

1:5000. Activity in this solution persisted for 25 minutes, against controls which continued for 2 to 4 hours. In the rabbit, two applications of ½ minute each, with an interval of 3 minutes, slowed the beat to 3 per second.

1:10,000. After 5 minutes' contact with this solution, activity persisted for upward of 2 hours. Under continuous contact complete cessation occurred in 20 minutes; resuscitation was possible. In the rabbit, four ½ minute applications with intervals of 3 minutes produced a slowing to 6 beats per second in some areas but not in others.

Cocain Hydrochlorid. Ten per cent solution stopped the action of most of the specimens immediately. The longest survival was 2 minutes. Attempts at resuscitation with Ringer's solution met with occasional success. In the rabbit, all motion ceased in 3 minutes. Six minutes of washing in Ringer's solution revived it in a few areas.

Five per cent. In the extirpated specimens, motion stopped in from 1 to 3 minutes. Attempts to revive it failed. In the rabbit, the speed of cilia was immediately slowed to half, and remained so for more than 2 hours.

Two and one-half per cent. In most eases, very little effect was noted from this solution. Continuous application for 1 hour was required to stop the cilia. The rabbit's mucosa showed blanching, but no change in ciliary motion.

Camphor. One *per cent* in liquid petrolatum. This drug had no apparent effect upon the living membrane. A strip of excised membrane showed normal activity at the end of 43 minutes. What has been said regarding the failure of liquid petrolatum to "wet" the membranes applies equally to the drugs here recorded which were dissolved in it.

Menthol. One *per cent* in liquid petrolatum. This drug had no apparent effect upon the living membrane. A strip of excised tissue immersed in it showed activity 1 hour and 24 minutes later.

When applied to the nasal mucous membrane of a rabbit for 9 months, 1% menthol in liquid petrolatum caused some degenerative changes.[19]

19. Fox, Noah: Effect of Camphor, Eucalyptol and Menthol on the Nasal Mucosa. Arch. Otolaryng., 11:48 (Jan.), 1930.

Thymol. One per cent in liquid petrolatum. This drug produced some irritation of the membrane immediately and slowed the activity of the cilia to 3 or 4 per second, stopping them in some areas altogether. A strip of excised tissue immersed in it showed complete cessation of ciliary activity in 6 minutes.

Menthol over long period in dilutions as low as 1% causes some degenerative changes; in 5% dilutions it causes definite destructive changes through all the layers of the nasal membrane.[20]

Five per cent eucalyptol and 5% camphor (but for that matter, liquid petrolatum alone) have a deleterious effect on the mucosa when used over a period of 9 months.

Although eucalyptol and camphor have practically no local effect on the nasal mucosa in concentrations up to 5%, menthol is a local irritant in dilutions as low as .5%.

It is the irritation of the thermal end organs which produces the sensation of coolness and patency, although there may be an actual reduction in the diameters of the air passages.[21]

Thus the menthol introduced into various products for soothing and cooling has precisely the opposite effect, and adds to the irritation instead of reducing it.

Mild Silver Protein (Argyrol). Ten per cent produced no demonstrable effect upon the living membrane, although both here and in the excised strip there was mechanical interference with streaming, caused by the clumping of the drug

20. Fox, N.: Effect of Camphor, Eucalyptol and Menthol on Nasal Mucosa. Arch. Otolaryng., 11:48 (Jan.), 1930.
21. Fox, N.: Effect of Camphor, Eucalyptol and Menthol on Vascular State of Mucous Membrane. Arch. Otolaryng., 6:112 (Aug.), 1927.

over the surface. Strips immersed in it beat from 13 to 54 minutes.

Silver Nitrate. Applications of silver nitrate are very destructive, the epithelium requiring as much as a week to regenerate. The cilia may not appear for 3 months afterward.[22]

Dibrom-oxymercuri-fluorescein (Mercurochrome). Two per cent aqueous solution. This drug produced some slowing of the cilia for an indefinite period in the living sinus after applications of 2 to 4 minutes respectively. Excised strips ceased moving from 8 to 17 minutes after immersion.

Sodium Ethyl-mercurithiosalicylate (Merthiolate). 1:1000. This solution applied to the living membrane for 2 minutes produced a pronounced slowing in the ciliary beat. Flushing with Ringer's solution for 2 minutes did not accelerate it again. A second application for 2 minutes caused it to stop entirely, nor could it be resuscitated with Ringer's solution.

1:10,000. In this strength, a two-minute application also caused some slowing, although less appreciable than with the stronger solution. Ringer's restored the rate practically to normal, but a subsequent application for 4 minutes stopped all motion and no resuscitation occurred. Excised strips were not subjected to this drug.

(A single rabbit was tested with streptolysate. After 2 minutes the cilia were beating at approximately the normal rate. A second application, this time for 4 minutes, resulted in a pronounced slowing. A repetition of the experiment in the opposite sinus gave approximately the same result. The particular lysate employed was preserved in 1:5000 merthiolate.)

22. Lillie, H. I. and Childrey: Effect of Silver Nitrate on the Nasal Mucosa of Rabbits. Arch. of Otolaryng., 17:1, 1933.

Alcohol. Although alcohol is not commonly applied alone to the nose nor to any appreciable extent in any nasal medicament, it was studied for the following reason: It is not an infrequent observation that persons imbibing alcoholic drinks—not necessarily in excess—experience a copious and sometimes viscous secretion of mucus from the nose and the sinuses. This phenomenon may occur a few minutes to a few hours after drinking the alcohol.

With the thought that this excessive secretion may serve a useful purpose in the eradication of deep-seated infections and that it may be produced by applying alcohol locally in weak solutions either by itself or as a vehicle for other drugs, it was included in this investigation.

It was observed that alcohol in any concentration *when diluted with distilled water* stops the ciliary beat in a few seconds, the rapidity depending only upon the strength of the solution.

Diluted with Locke's or with physiological sodium chlorid solution, however, it was surprisingly well tolerated. For example: *15%* on extirpated rabbit and guinea pig mucosa caused a slight slowing after 5 minutes. This was not progressive, however, and the cells were still in good condition and moving actively after 1 hour.

18% slowed the cilia at once and after 15 minutes practically all motility had ceased. Washing with Locke's solution restored the motility which continued for several hours, when the experiment was stopped.

20% stopped motility at once. If left in this solution for 2 or 3 minutes, some motility was still restored by immersion in

Locke's solution but some areas showed destruction of the surface.

5% alcohol in Locke's solution was applied in the living rabbit for over 2 hours without any appreciable effect.

10% in Locke's solution in the living rabbit showed no appreciable effect when the experiments were stopped at varying intervals over 1 hour.

20% in Locke's solution in the living rabbit showed a cessation of motility in 20 to 30 minutes and the cilia could not be resuscitated by Locke's.

When the membranes have been bathed over short periods of time in the stronger solutions of alcohol or longer periods in slightly weaker ones, the interference with ciliary activity seems to be due less to any paralyzing action on the cilia than to a disruption of the epithelium itself. There appear numerous small, fairly parallel crevices or cracks, apparently due to surface coagulation and shrinkage. Between these cracks motility often continues for many minutes. The same is noted with ether.

From this it appears that, should they prove useful, the dilute solutions of alcohol in isotonic salt solutions should be harmless in the nose in so far as ciliary action is concerned.

Sedatives. General anesthesia with sodium amytal or morphine and scopolamine has apparently no effect upon the ciliary beat, which in rabbits resembles in all respects that seen in animals killed by air injection or spinal section.

In the following experiments with ether, chloroform and nitrous oxide, because of clinical applicability, observations

were made upon the trachea as well as the sinus of rabbits. The method used was as follows:

The animal was anesthetized with urethane injected intraperitoneally. This produced profound anesthesia but had no visible effect upon the vigor or the speed of the ciliary beat. The trachea was exposed through a long median incision in the neck and was freed from surrounding structures for about 2 cm. With the animal on its back, the trachea was slipped over a narrow strip of metal fastened beneath the microscope objective in place of the stage. By removing a small piece from the front of the trachea, the interior could be readily observed through the microscope with the "Ultropak" attachment used for sinuses. The effects of the ether and chloroform vapor and nitrous oxide gas could be watched while they were being administered.

Ether. In a concentrated atmosphere of ether vapor, produced by wetting a ring of cotton placed around the open trachea, the cilia performed in a normal manner over any period of time.

If a current of ether vapor was blown against the epithelium through a small tube, the beat slowed rapidly and stopped while the blast continued. Motion could be suspended for several minutes in this manner but as soon as the vapor current no longer impinged directly upon the area, resuscitation occurred within a few seconds, followed by a short interval of highly exaggerated activity. This closely resembles the results of simply cooling the membrane and is attributed to the cooling effect of the ether vapor and not to any specific effect on the cilia.

Warming the ether apparatus did not alter the phenomenon but it also did not greatly increase the temperature at the

point of impact, where evaporation still reduced the temperature sufficiently to interfere with motility. In no experiment was there any indication that ether vapor itself caused any damage to the cilia.

In sharp contrast to this, however, was the effect of a small drop of ether applied directly to the membrane. In this case activity stopped promptly and permanently, due to injury to the surface cells. The cracking of the surface, similar to that noted under alcohol, occurred.

Chloroform. The fumes of this drug also were not found to have any demonstrable effect upon the cilia in the living animal. In this case, however, 2 minutes exposure of an extirpated strip of membrane to an atmosphere of chloroform vapor stopped all activity, which was only incompletely revived by washing in Locke's solution. This revival did not occur spontaneously without the washing in Locke's solution.

As in the case of ether, the chloroform itself in actual contact paralyzed the cilia at once. After chloroform they could be partly revived by quickly putting them under Locke's solution. This revival did not persist more than 10 minutes, after which there was complete immobility, apparently due to cell destruction.

A direct blast of chloroform vapor also stopped motility while the blast was in progress, which was likewise attributed to chilling, as recovery was immediate and motility vigorous.

Nitrous Oxide. No application of nitrous oxide to the cilia or to the animal had any demonstrable effect upon the ciliary motility, no matter whether the gas was concentrated or mixed with air. Animals kept under nitrous oxide anesthesia for 20 minutes and then killed with an overdose of the gas, showed

normal motility of the cilia, which were examined as quickly as it was possible to reach them after the death of the animal. To summarize, it would appear from the foregoing that the three anesthetics mentioned have no effect *per se* upon ciliary activity when administered in gaseous form.

The cold produced by their evaporation may paralyze the cilia while it continues. This was especially notable with ether and chloroform, although once or twice the cold produced by releasing the gas through the valve of the cylinder had somewhat the same effect.

Actual contact of the fluid, however, is disastrous to the membrane and it is therefore of the utmost importance to avoid accidental contact in the administration of anesthetics.

Wetting Agents. These agents, capable of reducing surface tension, have recently found a multiplicity of uses in industry, particularly in augmenting and maintaining wetting penetration and emulsification. Certain of them have appeared in soaps, tooth pastes and other products applicable to the human tissues. Numerous chemical agents have these characteristics in greater or less degree. Three of them were chosen for experimentation because they could be obtained in pure form and because one had already been shown to be nontoxic to rabbits in relatively large doses.

The three substances were decyl-benzene-sodium sulphonate, mono-butyl-diphenyl-sodium mono-sulfonate, and mono-butyl-phenyl-phenol-sodium mono-sulfonate. In each case, dilutions of .1% caused a disintegration of the epithelial surface practically at once. The microscopic field was filled with cells which had become detached from the surface and swam in the surrounding medium. No ciliary motility was noted on any

of these cells. The substitution of Locke's solution for distilled water gave practically the same result.

In the living rabbit, motility ceased in 3 minutes.

.01% in Locke's solution slowed the beat in 30 minutes and stopped it in 45. With the loss of motility there was also some disintegration of the membrane. In the living rabbit, no change was noted after 1 hour.

A .005% solution had no demonstrable effect upon the mucosa in the living animal after prolonged application.

There are several types of wetting agents, and it cannot be stated that the above effects are common to them all.

Inorganic Chlorids. Maxwell[23] finds that of the chlorids of lithium, ammonium, sodium, potassium, magnesium, calcium, strontium and barium in ⅛ mol. solutions, sodium chlorid is the most favorable to the prolonged life of cells and the preservation of their power to do mechanical work.

Alizarin: Oxylates. Wenner[24] irrigated the antrums of rabbits with chemicals such as alizarin and oxalates, which have the property of precipitating the calcium ions normally found in the cells of the mucosa. The cilia became paralyzed and infection followed from which the author concludes that calcium is necessary for normal ciliary movement.

23. Maxwell, S. S.: Effect of Salt Solutions on Ciliary Activity. Am. J. Physiol., 13:154 (Mar.). 1905.
24. Wenner, W. F.: Effect of Calcium-Precipitating Substances on Ciliated Epithelium of the Maxillary Sinus. J. Lab. & Clin. Med., 16:341, 1931.

Many of the drug experiments have been repeated by Frenckner[25] and Richtnér whose results, in the main, agree with the foregoing.

It should be pointed out that the data here recorded deal only with the rate and persistence of the ciliary beat and are not to be regarded alone as an index of therapeutic value.

One is impressed again with the extreme hardihood of the cilia and their persistence in functioning. The only drugs in the above list which promptly stopped their action are strong solutions of cocain and of epinephrin. Other drugs which stopped or slowed them in the extirpated strips are much less potent in the living membrane, constantly bathed in circulating body fluids.

On the whole, very little diversity of opinion exists among those authors who have studied the effects of drugs on cilia.

25. Frenckner, Paul und Richtnér, N. G.: Studien uber die Zilienbewegung in den oberen Respirationswegen bei Tieren und Menschen unter normalen und pathologischen Verhältnissen. Acta Otolaryng., 28:215, 1940.

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CHAPTER XVI

OTHER DEFENSES OF THE MUCOSA

NASAL MUCUS — VISCOSITY — HYDROGEN ION CONCENTRATION — HISTAMINE — BACTERIOSTASIS — POSTURE —FLUSHING — PERMEABILITY — REACTIONS OF INFLAMMATION—EFFECT OF PRESSURE UPON ABSORPTION —BASEMENT MEMBRANE—SPECIFIC PENETRABILITY—THE TUNICA PROPRIA—HISTIOCYTES.

In the foregoing pages much space has been devoted to the cilia albeit no more than is justified by their importance as a major defense against bacteria.

We come now to the other protective agencies inherent in the mucosa namely, the mucus itself, the epithelium, and the reactions of inflammation characteristic of all tissues and particularly of the reticulo-endothelial system.

NASAL MUCUS. Physical and chemical investigations into the nature of normal nasal mucus are difficult and figures derived from them are apt to be not quite accurate. The difficulty arises in the very small amount of mucus present upon the nasal surfaces under normal conditions. If this is encountered in sufficient abundance to accumulate on the nasal floor or elsewhere, where it may be picked up and subjected to reasonable tests, then *a priori* an abnormal state exists in the nose and presumably in the glands.

Artificial stimulation to increase the flow for purposes of analysis unfortunately has the effect of altering the composition of the mucus also.

The following figures are approximated from various sources:

Mucin, 2.5-3%
Salts, 1-2%
Water, 95-97%

Slight variations in the mucin content result in disproportionately large differences in viscosity.

Mucin is a gluco-protein containing a complex polysaccharid combined with a protein. This polysaccharid mucoitin sulphuric acid, is composed of four constituents—glucosamine, glucuronic acid, sulphuric acid and acetic acid. Mucins vary in their analysis; their solubilities and degrees of viscosity differ, the difference lying probably in the protein portion of the molecule.[1]

Likewise, mucus obtained from the nose differs in its essential characteristics from mucus obtained from any other source. Among other things, it has a much greater viscosity than the corresponding gastric mucin. Nasal secretion containing 1.26% protein has a viscosity equivalent to an 8.4% secretion of gastric mucin.[2]

VISCOSITY. Linton showed that desiccation or hydration produces rapid changes in viscosity due to the mucin concentration. "The logarithmic curve of the viscosities is a straight line. Calculations from nitrogen determinations indicate a normal mucin content of 2% to 3% in human nasal mucus. On this basis desiccation would result in a greater change in

1. Levene, P. A.: Hexosamines and Muco-Proteins. Longmans Green and Co., 1925.
2. Buhrmester, Catherine C.: Nasal Mucin. Ann. of Otol., Rhin. and Laryng., 45:687 (Sept.), 1936.

viscosity than would be secured by an equivalent amount of hydration."[3]

HYDROGEN ION CONCENTRATION. The average pH of the nasal secretions ranges from 7.60 to 8.40 and fluctuates momentarily. It is Hilding's observation that readings made quickly after obtaining the secretions more nearly approximate the smaller figure and that higher readings are obtained when the secretions are allowed to stand.[4] This change is presumably due to the loss of CO_2 absorbed in the nose from expired air.

The impression of various investigators that certain types of nasal infections exhibit characteristic variations in the pH, at present rests upon meager evidence.

Studies of the nasal mucus in disease conditions are more likely to be accurate than those of normal mucus because it is obtained in quantities.

The secretion from a cold is alkaline in the initial stage, and returns to its normal pH as the cold subsides. The initial physiological response of the nasal mucosa to stimulation does not vary, regardless of the inciting agent.[5]

Tweedie,[6] whose untimely death intercepted his very informative studies of the reaction of nasal mucus, summarized his ideas in a preliminary report as follows:

3. *Linton, C. S.*: Resistance of the Upper Respiratory Mucosa to Infection. Ann. of Otol., Rhin. and Laryng., 42.64 (Mar.), 1933.

4. Hilding, Anderson: Note on Some Changes in the Hydrogen Ion Concentration of Nasal Mucus. Ann. of Otol., Rhin. and Laryng., 43:47 (Mar.), 1934.

5. Buhrmester, Catherine C.: Further Studies in the Hydrogen-ion Concentration of Nasal Secretions. Arch. Otolaryng., 27:83 (Jan.), 1938.

6. Tweedie, A. R.: Nasal Flora and Reaction of the Nasal Mucus. J. Laryng. and Otol., 49:586 (Sept.), 1934.

"(1) The normal nose has a reaction varying from about pH 6.8 to 7.4 and, in the majority of cases, has a non-culturable bacterial content.

"(2) Cases of acute rhinitis up to three days old, vary in reaction from neutral to alkaline, but show no culturable content.

"(3) Cases of acute rhinitis, after this period, have an alkaline reaction and mostly show a culturable content with, generally, a more pronounced growth on an alkaline than a neutral medium.

"(4) In cases of recovered acute rhinitis, the reaction again becomes neutral and the chances of culturable content begin to diminish.

"(5) In cases of chronic rhinitis, without other general symptoms, the reaction is usually neutral and the mucus more often sterile than not.

"(6) In eases of chronic rhinitis, associated with sinusitis and polyp formation, the reaction may be either neutral or alkaline and there is a culturable content in about half the eases, and on a medium with a reaction usually corresponding to that of the mucus.

"(7) In 'clean' cases of post-operative or traumatic rhinitis, the reaction is normal and there is no culturable content.

"(8) A culturable bacterial content may be restricted to one side of the nose. The organisms found have been haemolytic and non-haemolytic streptococci and, occasionally, staphylococcus aureus."

HISTAMINE. Calculated on the basis of the dry weight of the tissues, polypoid tissue contains more histamine than normal

membrane. Nasal secretions from persons with allergic rhinitis contain less histamine-like substance than do polypi and have no depressor activity when intravenously injected.

The increase in mineral content of the nasal discharge resulting in increased permeability and an altered acid-base equilibrium may be important factors in the production of allergic reactions.[7]

BACTERIOSTASIS. For forty years observers have been in virtual accord regarding the role played by the nasal mucus in repelling infection. Despite occasional recent experiments it is generally held that the action of the mucus is mechanical and that it has no specific immunizing powers. Wagner[8] was able to cultivate bacteria on artificial media, containing mucin.

What difference of opinion exists may be due in part to the fact that the bacteriostatic property varies in different species. Apparently the nasal mucus of dogs has little or no inhibitory effect upon bacteria, in fact supports a moderate growth, while secretions from the sinuses of rabbits show an appreciable if transient antibacterial effect.[9]

It has frequently been said that the mucosa of the normal nasal sinus is sterile. This is not quite accurate. Cultures made by the method of Linton[10] and grown under aerobic

7. *Buhrmester*, Catherine C. and Wenner, W. F.: Presence of a Histamine-like Substance in Nasal Mucosa, Nasal Polypi and Nasal Secretion. *Arch. Otolaryng.*, 24:570 (Nov.), 1936.

8. Wagner, Henry Lewis: Natural Immunity of the Mucous Membranes of the *Respiratory Tract. Trans. Amer.* Laryng. Assn., 1898, p. 61.

9. Linton, C. S.: Bacteriostatic Properties of the Secretions of the Sinuses. Arch. of Otolaryng., 15:190-201 (Feb.), 1932.

10. Linton, C. S.: An Improved Method of Collecting Nasal Cultures. Ann. of Otol., Rhin. and Laryng., 41:141-142 (Mar.), 1932.

and anaerobic conditions have often been found to contain some bacteria.[11] Dust particles can also be recovered at times. The sinus, however, clears itself quickly of such foreign material.

POSTURE. Posture can have little if any effect upon drainage so long as the mucosa is healthy. The mucus which coats the membrane is spread in an exceedingly thin, tenacious film on the surface of the rapidly moving ciliary mat, as we have seen. In such a system gravity has little effect compared to surface tension and ciliary action.

Apparently it is only after this mechanism is somehow upset so as to increase the bulk of surface mucus that gravity enters into the equation. This may be due either to an increase in production of secretion or to an obstruction of the ostium preventing its escape.

The increased film of moisture is beyond the effect of ciliary action; it accumulates at the bottom of the sinus cavity. If the inflammation advances, change of posture can aid drainage for only so long as the ostium remains open or there is an artificial opening. Posture, therefore, so far as spontaneous drainage is concerned, plays an exceedingly limited part.

Bacteria and particulate matter find their way into the alveoli of the lung with great difficulty, even when injected in large numbers, provided that they are in a dry state. In this condition they are invariably caught by the mucus of the lesser bronchioles and expelled by the trachea. However, if they are introduced in fluid suspensions, some of the material is enabled to reach the alveoli, where no expulsive

11. Linton, C. S.: A Comparative Study of the Bacterial Flora of Clinically Normal Nasal Sinuses. Ann. of Otol., Rhin. and Laryng., 39:779 (Sept.), 1930.

mechanism exists, and where, in the case of bacteria, infection takes place.[12] For this reason it is vitally important in evaluating experiments dealing with pulmonary infections from above to determine under what conditions the infecting organism reaches the lung.

FLUSHING. Besides acting either as a belt conveyer or a possible antiseptic, the nasal mucus may protect the membrane in still another manner. Under the irritative stimulation of bacteria, capable of paralyzing and penetrating the ciliary layer, quantities of mucus speedily flood the area—mucus much too thin to have any dragging action but in sufficient quantity to wash away the invader. Thus it happens that nasal mucus, thin enough to be scattered by sneezing, is also apt to be loaded with bacteria of high virulence.

PERMEABILITY. Those forces which underlie the penetrability of the cell membrane, rendering it at one moment impervious to bacterial penetration and at the next susceptible to it, still remain a mystery. No one has interested himself more in the problem than Jonathan Wright and no one was less sanguine of its early solution. In a letter to the author, dated May 18, 1922, he wrote: "The most striking phenomenon of surface penetration, which I believe is governed by the surface tension as modified by a change in the biochemics of the lipoids or fat-like constituents of the surface epithelium, is the perfect ease with which bacteria in the tonsil crypts penetrate the loose end of an epithelial cell 'shaling off' from its attachment but still alive at the attached end, the latter being free of bacterial life and the loose end showing it in the cocci which are often present in large numbers. When

12. Barclay, A. E., Franklin, K. J., and Macbeth, R. G.: Roentgenographic Studies of the Excretion of Dusts from the Lungs. Amer. Jour. of Roentgenology and Radium Therapy, Vol 39, No. 5 (May), 1938.

the animal body dies bacterial absorption rapidly takes place from all the mucous surfaces . . . A sufficiency of biochemical and biophysical knowledge already exists to establish the reality of the process—that the primary step in the infections of the animal body is one of a change in the relation between the surfaces of the host and the bacterial life which exists upon it. The contact of the two may always have existed but penetration depends upon that biochemical change, or biophysical if you will, and not upon the mere incidence of bacterial life upon the surface of the host. Needless to say this question is calculated to revolutionize our ideas of the etiology of disease if it is solved as I know it eventually will be . . . I do not expect to see it in my day."

At least one of Wright's disciples has made some progress in the solution of this fundamental problem, and it will repay anyone to follow the works of Stuart Mudd.[13]

Nasal infections, frequent and persistent, are the common lot of civilized man or at least that part of him dwelling in centers of dense population.

Carmody[14] says "the infant does not exist who has reached the age of one year without the so-called acute cold. The number of attacks and the duration of trouble before a chronic sinus change takes place depend upon individual variations, due to susceptibility, virulence of infection, etc. In some cases only one attack occurs, in others many, before sufficient change takes place to be noted radiographically. Infection early in life

13. Mudd, Stuart: The Penetration of Bacteria Through Capillary Spaces. Jour. Bacteriol., Vols. 8 and 9, 1923-24 and various titles in the Jour. of Exper. Med. and the Jour. of General Physiol. from 1925 to 1931.

14. Carmody, Thomas E.: The Development of the Sinuses After Birth. Ann. of Otol., Rhin. and Laryng., 38:130 (Mar.), 1929.

of maxillary and ethmoid sinuses interferes with the development of frontals. Infection of the surface of the mucous membrane will not cause a radiographic shadow, while deeper infections will."

REACTIONS OF INFLAMMATION. Aside from the specialized action of the cilia and the mucous blanket, responses of the nasal tissue to irritation and infection are comparable to those found elsewhere in the body.

The initial reaction is ordinarily a transient ischemia, reflex in character.

The physician rarely encounters the infection in this stage. Air passages are widened, and the patient is as yet unconscious of his disease. This stage, however, persists no longer than an hour or two, to be followed shortly by an arterial hyperemia. The membrane is red and moderately swollen; respiration is somewhat impeded but thus far the nasal secretions have not changed much in character.

Close upon the heels of this arterial engorgement follows venous stasis; the tissues are distended, the air flow is impeded and the mucosa takes on a bluish hue.

The reaction has now reached the end of the vascular stage. Diapedesis begins, the areolar tissues become distended with fluid, phagocytes of various kinds come into action, fluids and cellular elements are thrown out upon the surface: the exudative stage is in progress.

Whether resolution or chronicity ensues now depends upon the effectiveness of the various defense mechanisms presently to be discussed.

During the exudative stage the subepithelial layers of the mucosa become immensely distended due to vascular engorgement and the mobilization of fixed and wandering phagocytic cells. When such thickening takes place in the nasal chamber obstruction to breathing ensues; when it occurs in the sinuses retention follows. In this location the patient may be quite unconscious of it, or it may cause him acute pain.

EFFECT OF PRESSURE UPON ABSORPTION. The effects of even slight pressure in confined cavities upon the rapidity of absorption is exemplified by the incision of the ear drum in acute middle ear infection. The immediate reaction of the patient to such an opening is well known. Not only is the pain relieved but the fever falls precipitately and the accompanying malaise disappears almost at once. There is no comparable reduction in the amount of infection to account for this change nor is there a reduction in the area involved. Only the pressure falls.

BASEMENT MEMBRANE. The basement membrane underlying the nasal epithelium varies considerably in thickness, and may be detected in any part of the nose. If it is more than barely discernible there will probably be found evidence of some chronic changes in the membrane. It is composed of a dense, fairly homogeneous layer of collagen immediately beneath the epithelium and is traversed by numerous canaliculi, through which leucocytes and possibly tissue fluids make their way to the surface.[15]

Any pronounced thickening may be regarded as a fibrosis resulting from chronic irritation or inflammation.

15. Shambaugh, George E. Jr.: The Basement Membrane in the Mucosa of the Upper Respiratory Passages. Arch. Otolaryng., 13:556 (Apr.), 1931.

SPECIFIC PENETRABILITY. Whatever may be the inherent protective capacity of the upper respiratory mucosa, there is evidence to show that sufficiently virulent bacteria may penetrate it without the intervention of other influences tending to reduce resistance. Washing of virulent strains of hemolytic streptococcus, free from products of its growth on blood agar, serves only to impede and delay its penetration but does not prevent it.[16]

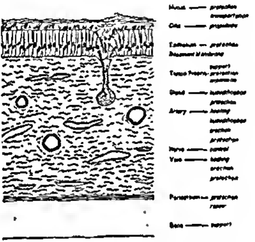

Fig. 78. Components of the mucosa and their individual functions.

The products of bacterial growth under certain conditions paralyze ciliary activity, although this paralyzing action is no criterion as to the actual virulence of the bacteria.

The pathogenic organism which has had the hardihood to withstand or evade the sweeping action of mucus and cilia and the epithelial cells, now encounters a second line of defense, namely, the connective tissue layer—the tunica propria.

16. Linton, C. S.: Resistance of the Upper Respiratory Mucosa to Infection. Ann. of Otol., Rhin. and Laryng., 42·64 (Mar.), 1933.

Unlike the front-line mechanisms which are in action and on guard day and night, in health as well as in sickness, this zone is normally on a peace-time basis and mobilizes its combat units only under stress of mechanical irritation, chemical attack, or bacterial invasion.

THE TUNICA PROPRIA. The cellular elements of this connective tissue fall into five classifications:

(1) Fibroblasts
(2) Ameboid wandering cells
(3) Undifferentiated mesenchymal cells
(4) Mast cells
(5) Resting wandering cells, or "histiocytes"

HISTIOCYTES. Histiocytes are scattered among the fibroblasts, and in some regions of the body, especially the more vascular ones, equal them in number. They are fusiform or ovoid and often irregular in outline, but are not ameboid. The chromatin particles are coarser than those of the fibroblasts, and both these and the protoplasm stain dark. It is characteristic of histiocytes that the vacuoles in the living cells take up and store insoluble particulate matter.

As part of the process of inflammation these cells mobilize and function as phagocytes even before the arrival of polymorphonuclear leucocytes or lymphocytes. At such times their movements become ameboid.[17]

Evidence exists to indicate that endothelial cells may undergo a transformation into wandering cells, but there is divergence of opinion whether fibroblasts under the stimulation of the inflammatory process may do the same. It has been held that

17. Maximow, A. A.: Textbook of Histology. Saunders, Phila., 1930, p. 48 et seq

endothelial cells become monocytes or histiocytes depending upon their entering the blood or the connective tissues.

When an inflammatory process is going on, histiocytes become free moving polyblasts as do also certain other cells, notably reticular cells of the lymphoid organs, bone-marrow and spleen pulp. They may undergo further modification into giant cells, the epithelioid cells of the tubercule, or fibroblasts or they may revert to their original type as histiocytes. At the height of their activity as phagocytes, they function side by side with the monocytes and lymphocytes of the blood.

This mechanism sometimes characterized as the "reticulo-endothelial system" has a part in the second-line defense of the mucosa. A further discussion of this system would lead us into the realms of general immunology and pathology. The interested reader will find among the titles of the supplementary references immediately following, material to meet his requirements.

From this point on, the outcome of the infection rests with the selectivity of the invading organism for specific tissues and the systemic immunity of the patient, subjects which also do not come within the province of this discussion.

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CHAPTER XVII

VASCULAR AND LYMPHATIC REACTIONS

VASCULAR ARCHITECTURE — ABERRATIONS—ERECTILE TISSUES—LYMPHATIC NETWORK—DRAINAGE—PARTICULATE MATTER AND THE EPITHELIUM—PARTICULATE MATTER AND THE LYMPHATICS.

Normally the mucosa of the airways is a pale vermilion, the capillary system being filled far short of its capacity. In the sinuses there is so little blood that the color of the mucosa is pale yellow.

VASCULAR ARCHITECTURE. The architecture of the superficial nasal vessels and especially that of the turbinates bears a striking resemblance to the parallel pipes of a heating or cooling system. The vessels lie neatly arranged side by side with spaces between, which are scarcely wider than their own diameters.

Grossly, in the injected specimen, the turbinate presents an unbroken and very finely striped surface of blood-containing vessels and looks a little like the radiator of an automobile.

Unlike the latter, however, fluid does not necessarily flow from end to end of the apparatus. Numerous communications exist at short intervals between arteries and veins.

The most advanced investigations relative to these structures in mammals have been made by Professor Swindle of

Marquette University,[1] who has developed an ingenious method of injecting them. He has had as his co-worker, L. C. Massopust, whose unique skill in the field of infra-red photography has played a large part in the interpretation of the specimens.

With reference to the distribution of their nasal blood vessels mammals may be divided, according to Swindle, into two groups, namely, those in which a venous-blood-containing layer overlies an arterial-blood-containing one, and those in which the layers are reversed. In each type the mucosa contains also a third stratum deeper than the other two, which functions only during prenatal and early postnatal life. At this period it conducts venous blood but in the adult becomes a non-functioning potential space. The venous and arteriovenous anastomoses through which it was connected to the other layers during its functional existence vanish.

The two persisting strata are connected by vertical venocapillary and arteriocapillary anastomoses and a general network of capillaries.

For convenience Swindle designates those in which the venous layer is the more superficial as "V/A mammals," those in which the arterial layer is the more superficial as "A/V mammals."

In the V/A type the characteristic vascular arrangement extends to the mucous lining and the skin outside the nasal

1. Swindle, P. F.: The Architecture of the Blood Vascular Networks in the Erectile and Secretory Lining of the Nasal Passages. Ann. of Otol., Rhin. and Laryng., 44:913, 1935.—The Architectural Arrangement of the Nasal Arteries and the Angioarchitectural Basis of the Common Cold. Trans. Amer. Laryng. Rhin. and Otol. Soc., 1936, p. 309.—Nasal Blood Vessels Which Serve as Arteries in Some Mammals and as Veins in Some Others. Ann. Otol., Rhin. and Laryng., 46:600, 1937.

Fig. 79. Arrangement of blood vessels upon the surface of the concha. (From the collection of Professor P. F. Swindle, reproduced with his kind permission. Infra-red photograph by Mr. L. C. Massopust.)

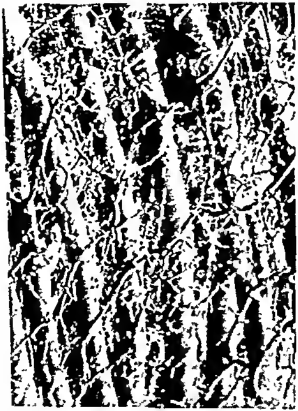

Fig. 80. High-power photograph of the blood vessels of the concha. From the collection of Professor P. F. Swindle, reproduced with his kind permission. Infra-red photograph by Mr. L. C. Massopust.

passage. In the A/V type this is not the case; the reversal to the V/A arrangement occurs at the anterior and posterior margins of the nasal linings. Here the deep stratum consists of arteries some or all of which persist into adult life, and the arterial anastomoses persist as helicine arteries. The arteriovenous anastomoses undergo complete metamorphosis and become capillaries, venocapillary anastomoses and postreticular endarteries.

Man belongs to the V/A type.

It requires only a glance at these amazing photographs to appreciate the efficiency of the nose as a heating and humidifying mechanism, and at the same time to be impressed with the potentialities for trouble when such a system, through a derangement of its controlling nervous supply either overflows or collapses.

When the nasal mucosa is deprived of its air currents, as by a total laryngectomy, the blood supply gradually becomes much reduced.[2]

ERECTILE TISSUES. The supply and distribution of the blood of the erectile tissues of the turbinated bodies is regulated somewhat by the swelling of the radicle artery impinging on the vein as they lie close together or cross one another in bony canals. But this alone does not meet the requirements of the nose. A more delicate control is effected through the agency of smooth muscle cells distributed about the arterial and venous twigs and their innervations.

The erectile tissue in the nasal mucosa consists of spaces obtaining their blood supply from small surface capillaries

2. Sternberg, H.: Die Veränderungen der Nasenschleimhaut bei angeschalteter Nasenatmung. Zeitschr. für Hals- Nasen u. Ohrenh., 7:432, 1924.

originating from the postnasal artery and emptying into the submucosal veins. The walls of these vessels are plentifully supplied with elastic tissue and muscle fibers reaching into the lumina as trabecular prominences. These muscle fibers are developed to a degree ordinarily associated with arteries.[3]

Various extrinsic factors influence the states of dilatation and contraction of the vessels. Compression of the common carotid artery causes only temporary loss of volume, which is soon overcome by collateral circulation. Compression of the neck veins dilates the nasal vessels. Deep narcosis and some laryngeal reflexes also result in dilatation. Exercise, sudden noises or pain may bring about constriction. Many drugs affect the nasal network, whose special actions are well known.[4]

It is possible to bring about a contraction of the erectile tissue by means of epinephrin and then to precipitate a local red spot by irritation with a probe. This dual vascularization accounts for the frequent discrepancies between color and state of engorgement, although a pronounced edema may simulate blood engorgement which does not exist.

When a simultaneous contraction of the two systems takes place it is indicated by a pallor of the mucosa. Collapse of the erectile tissue is not always accompanied by pallor. The subepithelial capillaries may be at the same time engorged, the inference being that the two systems maintain a separate reactivity to nervous as well as external stimuli.[5]

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3. Gruenwald, cf. Muck, O.: The Nature and Clinical Significance of a Nasal and Vasomotor Reflex-Phenomenon. Ztschr. f. Hals-, Nasen-u. Ohrenh., 12:311 (Jan.), 1926.

4. Sternberg, H.: Contribution to the Physiology and Pathology of the Respiratory Mucosa. Ztschr. f. Hals-, Nasen- u. Ohrenh., 12:340 (Nov.), 1925.

5. Sternberg, H.: *Pharmacologic Reactions in the Erectile Tissue and Subepithelial Net of Capillaries in Nose: Vasomotor Nerve Supply of this Vascular System.* Monatschr. f. Ohrenh., 63:390 (Apr.), 1929.

LYMPHATICS. A dense network of lymphatic capillaries immediately underlies the epithelium. The dimensions of these vessels are somewhat proportional to the thickness of the tunica, of which they form a part. Like the glands, they are scant where the mucosa is thin and abundant where it is thick. In the turbinates the vessels are irregular in size and distribution.

The network is a closed system anastomosing over the entire nasal mucosa.

The following arresting paragraph is from Hartz:

"The proper conception of the lymphatics as a circulatory system was first formed by U. Rudbeck of Sweden, in the year 1659. As was the custom at that time, he made a public demonstration of the lymphatic circulation in animals which was witnessed by Queen Christina. W. Hunter, of England, supporting Rudbeck, wrote upon the origin and use of the absorbent lymphatic vessels, while Harvey to the end of his life refused to believe in the newly found system of vessels, although he had only a few years before discovered the blood circulation. It is of interest to record that one de Peissic, of France, a high executioner of criminals, aided in the demonstration of human lymphatics. Prisoners sentenced to be hanged were carefully kept in ignorance of their impending fate, and about one and one-half hours before the time of execution were given a hearty meal, which they relished with zest. Immediately after the execution their bodies were taken to the anatomical institute for investigation. The chyle vessels could be seen full of the recent food and their origin and distribution studied. The contents—a milk-white fluid—was collected for examination."[6]

6. Hartz, Henry J.: The Lymphatics of the Nose and Naso-Pharynx, with Consideration of the General Lymphatic System. Trans. Amer. Acad. of Ophthal. and Otolaryng., 1911, p. 119.

Lymphatic drainage of the external nose is in two directions. The superior lymph vessels from this region pass to the anterior auricular glands thence to the parotid and upper deep cervical glands. The inferior group pass via the submaxillary lymph glands thence also to the superior deep cervical glands.

Drainage. The internal drainage is divided between two collecting trunks. The anterior trunk anastomoses with vessels of the external nose and empties into the submaxillary and deep cervical systems; the posterior trunk unites with the lymphatics of the sinuses just below the orifice of the eustachian tube. Here there is a very abundant network of lymphatics communicating laterally and downward with the deep superior cervical glands. Two to four vessels remain close to the side of the pharynx to empty into the lateral retropharyngeal gland, which itself empties into the deep cervical gland.

Apparently the lymph capillaries from the sinuses drain not only through the ostia but directly through the bone as well. It was shown by André[7] that the lymphatics of the perimeningeal spaces and the lymphatics of the nasal fossae connect through small canals traversing the cribriform plate of the ethmoid bone.

The canals so connected appear to be confined to the olfactory area.

Dyes and radiopaque fluids injected into the subarachnoid space pass first into the perineural areas and later into the lymphatics of the nasal mucosa. India ink injected into the meninges covering the olfactory bulb appears in the nose completely enclosed in the perineural spaces, while the lymphatic

7. André, J. M.: Contribution à l'étude des lymphatiques du nez et des fosses nasales. *Thèse de Paris*, 1905.

network and the other structures of the nasal mucosa remain free of it.[8]

PARTICULATE MATTER AND THE EPITHELIUM. McMahon has made a careful study of the behavior of intact and broken epithelium toward particulate matter, and the disposal of the latter when injected subepithelially. His findings are best summarized in his own words:

"1. Carbon particles in suspension do not pentrate the intact ciliated or squamous epithelium of the turbinates of the rabbit after thirty minutes' to six hours' contact.

"2. Carbon particles in suspension do not penetrate the intact or broken epithelium of the antrum of the rabbit after six hours.

"3. Neither the ciliated epithelial nor the squamous cells of the turbinates are phagocytic for carbon particles.

"4. Neither the attached nor free ciliated epithelial cells of the antrums are phagocytic for carbon particles.

"5. Particulate matter spreads through the subepithelial tissues of the mucosa of the turbinates and antrums in four ways: (1) through the tissue spaces; (2) through the capillary lymphatics of the stroma; (3) through the perivascular lymphatics; (4) through the main lymphatics.

"6. The direction of spread of particulate matter in the turbinates is from anterior to posterior, and not from turbinate to turbinate, or from the turbinates or antrums of one side of the nose to those of the other.

8. Novelli, D.: Communications Between Subarachnoid Spaces and Nasal Mucosa (Sulle comunicazioni fra spazi subarachnoidei e mucosa nasale). Boll. delle Malatt. Orecch. Gola, Naso, 51:131 (Apr.) 1936

"7. Particulate matter is phagocytosed in the subepithelial tissue of rabbits by the histiocytes, the fibroblasts and fixed connective tissue cells, the monocytes and the vascular endothelium. Phagocytosis is more complete after twenty-four hours than after six hours.

"8. Phagocytosis of particulate matter by fibroblasts, histiocytes or monocytes is not activated by infection or by a bacteriophage.

"9. Polymorphonuclear leucocytes, whether free or in the subepithelial tissue, do not phagocytose particulate matter."[9]

PARTICULATE MATTER AND THE LYMPHATICS. Larsell tells us that there are four avenues by which material in solution or suspension may travel from the nose to the bronchial and mediastinal lymph nodes. They are (1) the trachea, (2) the combined path of the lymph nodes, tracheal lymph duct and blood vessels through the right side of the heart and the pulmonary bed, (3) the purely hematogenous path and (4) lymph spaces and channels in the visceral cervical space, the dorsal wall of the esophagus, the prevertebral fascia, and related structures, which communicate with the anterior part of the mediastinum. To the last mentioned he attributes little significance, for the reason that bacteria escaping from the retropharyngeal region into adjacent tissue spaces are probably phagocytosed by the numerous histiocytes in the looser tissues before they have proceeded very far.[10]

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9. McMahon, Bernard J.: The Spread and Phagocytosis of Particulate Matter in Nasal Mucous Membrane of the Rabbit. Ann. of Otol., Rhin. and Laryng., 42:660 (Sept.), 1933.

10. Larsell, Olof, with the collaboration of Fenton, Ralph A.: Lymphatic Pathways from the Nose. Arch. of Otolaryng., 24:696-713 (Dec.), 1936.

The continuity of the connective tissue spaces with the mediastinum, however, makes this an occasional pathway of infection. This is particularly true of the prevertebral space.[11]

Le Gros Clark[12] dropped a 10% solution of potassium ferrocyanide and iron ammonium citrate into the nasal cavities of rabbits, which he killed at intervals of one, two or three hours, washed and fixed in formalin. In one of his rabbits, killed one hour after treatment, the solution was found to have reached, among other things, "the deeper tissues in the orbit and the cellular tissue among the nuchal muscles, even extending on to the occipital aspect."

11. Proetz, Arthur W.: A Syndrome of Pain and Paralysis Arising from Inflammations of the Prevertebral Space. Ann of Otol., Rhin. and Laryng., 44:371 (June), 1935. Also—Report to the III Internat'l Congress, Berlin, 1936.

12. Clark, W. E. LeGros: Anatomical Investigation Into the Routes by Which Infections May Pass from the Nasal Cavities into the Brain. Reports on Public Health and Medical Subjects, No. 54, London, 1929, p. 13.

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Sternberg, H.: The Capillary Blood Supply of the Mucosa of the Airways and Its Physiologic and Pathologic Significance. Ztschr. f. Hals-, Nasen- u. Ohrenh., 18:593, 1927.

Trotter, H. A.: The Surgical Anatomy of the Lymphatics of the Head and Neck. Ann. Otol., Rhin. and Laryng., 39:384 (June), 1930.

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Looney, W. W.: Lymphatic Drainage of the Head and Neck. Ann. of Otol., Rhin. and Laryng., 44:33 (March), 1935.

CHAPTER XVIII

NEURAL REACTIONS

SENSORY INNERVATION—SPHENOPALATINE GANGLION—AUTONOMIC NERVOUS SYSTEM—"VIDIAN" NEURALGIA—SNEEZING — SLUDER'S "LOWER HALF" HEADACHE —MIGRAINE—REGULATORY FUNCTION OF INSPIRED AIR.

Aside from the sense of smell, the neuro-physiology of the nose deals for our purposes chiefly with the regulation of the mechanisms enumerated in the preceding chapters.

In its clinical aspects, it plays so important a role in the production of pain and headache, that one may digress for a moment from the physiological theme to dwell briefly upon the nature of these distressing symptoms.

Anatomically the nerves of the nose have been too often described to require more than an introductory mention. The experimental work cited, however, is recent and constitutes an important contribution to our understanding of nasal physiology.

SENSORY INNERVATION. The sensory nerves of the nose all stem from the first and second divisions of the trigeminal nerve.

The anterior ethmoidal nerve, a branch of the ophthalmic division, enters the nose from the dorsal surface of the cribriform plate through the nasal fissure at the side of the crista galli. Branches from this nerve supply the frontal and anterior ethmoidal sinuses.

Dividing into median and lateral branches, the nerve supplies the extreme ventral portions of the septum and the lateral wall as far back as the tips of the middle and inferior turbinated bodies. A terminal branch of the lateral ramus passes between the nasal bone and the lateral nasal cartilage to supply the skin of the tip of nose, and a portion of the ala. This external distribution is sometimes of use in establishing the participation of the first division in a trigeminal neuralgia.

Branches of the second division pass in relationship to the nasal (sphenopalatine) ganglion and are distributed together with branches of that ganglion.

It was stated by Müller[1] and subsequently by Larsell and Fenton[2] on anatomic grounds, that the unmyelinated fibers in both the maxillary and the vidian nerves pass through the sphenopalatine ganglion without interruption. Kuré and Sakurasawa,[3] shortly after, demonstrated experimentally that these fibers disappear after extirpation of the superior cervical ganglion, and hence are sympathetic or thoracico-lumbar autonomic fibers.

SPHENOPALATINE GANGLION. The results of Christensen's careful studies of this ganglion and its components, he sets forth as follows: "The sphenopalatine ganglion cells are mainly multipolar. Occasional ones have one or two conspicuous processes, but show very minute cytoplasmic processes; consequently, they probably should be regarded as multipolar and efferent in function. The nerve of the pterygoid

1. Muller, L. R.: Die Lebensnerven, 2nd Ed., Berlin, 1924.
2. Larsell, O. and Fenton, R. A.: Embryology and Neurohistology of Sphenopalatine Ganglion Connections. Trans. Am. Otol. Soc., 1928.
3. Kuré, K. and Sakurasawa, F.: Über die parasympathischen Fasern fur das Ganglion Sphenopalatinum und über den Verlag der Sekretionsfasern für die Tränendruse. Zeitschr. fur Zellforschung und mikr. Anat., Vol. 9, 1929.

canal which conveys preganglionic fibers to the sphenopalatine ganglion represents a composite made up of some large and medium-sized and many small myelinated fibers from the greater superficial petrosal nerve and a few myelinated and many unmyelinated fibers from the deep petrosal nerve. The unmyelinated fibers are mainly sympathetic, since they degenerate following the removal of the superior cervical sympathetic ganglion. The small myelinated fibers are mainly preganglionic. The remaining fibers are afferent, having their origin mainly in the geniculate ganglion."

The sphenopalatine nerves convey many myelinated and a few unmyelinated fibers to the sphenopalatine ganglion. The myelinated fibers are sensory and have their origin in the semilunar ganglion. The unmyelinated fibers are probably mainly sympathetic.

The lateral nasal and nasopalatine nerves carrying fibers from the sphenopalatine ganglion, are made up of large, medium-sized and small myelinated and many unmyelinated fibers. The unmyelinated fibers are in part parasympathetic fibers arising in the sphenopalatine ganglion and in part sympathetic fibers which traverse it. The myelinated fibers are mainly components of the Vth and VIIth nerves, which traverse the sphenopalatine ganglion.

"The nasociliary nerve," he continues, "through its ethmoid branch supplies large, medium-sized and small myelinated and unmyelinated fibers to the nasal mucosa. Some of the unmyelinated fibers are sympathetic, since they undergo degeneration following extirpation of the superior cervical sympathetic ganglion. The remaining fibers, including unmyelinated, small myelinated and in a few instances large myelinated fibers

probably are sensory and have their origin mainly in the semilunar ganglion. The nasal nerves from the sphenopalatine ganglion and the nasociliary nerve also include some afferent components of the vagus and the upper thoracic spinal nerves."[4]

These findings, the author points out, do not support the assumption that autonomic ganglia include afferent or sensory ganglion cells, but these ganglion cells, like those in the ganglia of the sympathetic trunks, are essentially efferent. The afferent functions, which have sometimes been attributed to these ganglia particularly the sphenopalatine, can be explained satisfactorily on the basis of the afferent fibers which traverse them.

Unmyelinated fibers from the deep petrosal nerve, the internal carotid plexus and the superior cervical ganglion pass through the sphenopalatine ganglion and into the zygomaticotemporal nerve. These are either vasomotor or direct secretory fibers from the superior cervical ganglion to the lachrymal gland. There is some evidence that the sphenopalatine ganglion sends similar branches.[5]

It undoubtedly supplies secretory fibers to the mucous glands of the nasal cavity. Kuré and Sakurasawa believe that these preganglionic fibers reach the ganglion through its maxillary connections as well as through the great superficial petrosal nerve, and base their opinion upon the fact that nasal secretion, which continues after section of the vidian nerve and the chorda tympani, promptly ceases with the extirpation

4. Christensen, Kermit: The Innervation of the Nasal Mucosa, with Special Reference to Its Afferent Supply. Ann. of Otol., Rhin. and Laryng., 43:1066 (Dec.), 1934.

5. Larsell, O. and Burns, E. M.: Some Aspects of Certain of the Cranial Nerves. Ann. of Otol., Rhin. and Laryng., 40:661 (Sept.), 1931.

of the sphenopalatine ganglion whose only remaining connection with the central nervous system is the maxillary nerve.

AUTONOMIC NERVOUS SYSTEM. A large proportion of the nasal ailments of nervous origin have for their basis a derangement of the autonomic nervous system. This system, though elaborately associated with the cerebral system, is separate from it and is the counterpart, in fact the lineal descendant, of the filamentous networks to be found in the very primitive organisms. It functions below the level of consciousness, is not subject to control of the will and serves to carry on the purely vegetative processes, such as vascular tone, the action of smooth muscle fibers and the regulation of glandular secretion. It therefore enters largely into the emotional states which accompany these bodily functions.

As to the likelihood of its conducting pain impulses, Larsell, Barnes and Fenton who sectioned the maxillary nerve, thus excluding the Vth, and found that faradic stimulation of the sphenopalatine region produced marked vasoconstriction in the ear through impulses which must have traveled via the great superficial petrosal or possibly the deep petrosal nerve, feel that the pain may be produced by the ischemias resulting from the stimulation, and not by any direct pain transmission from the nose.[6 7]

"VIDIAN" NEURALGIA. It was Vail's contention that the term "vidian neuralgia" should supplant "sphenopalatine ganglion neuralgia" chiefly on the ground that he was sometimes able to set off the pain by irritating the vidian nerve

6. Fenton, Ralph A.: Pathways of Referred Pain from the Nose. Amer. Jour. of Surgery, 42:194-198 (Oct.), 1938.

7. Larsell, O., Barnes, M. S. and Fenton, R. A.: Relation of Irritation in Region of Paranasal Sinuses to Certain Vasomotor Changes. Arch. Otolaryng., 27:266, 1938.

through an opening into the sphenoid sinus; and further that he could control this pain by cocainization in the same spot.[8]

As a matter of fact the pain in given cases may arise from either the ganglion or the nerve, without the other. This is explained by the fact that pain impulses can pass in either direction from either source, *i.e.*, to the face or to the geniculate ganglion. This pain again can sometimes be controlled by the cocainization of one whilst cocainization of the other produces no effect.

SNEEZING. Important as a protective measure is the nasal reflex, sneezing. This is part of a more or less generalized reflex response to an abnormal stimulation of the nasal mucosa, which includes twitching of the nose and the face, blinking, tearing and a hypersecretion of watery nasal mucus. It is often accompanied by a sudden and transient engorgement of the nasal blood spaces.

It is not possible to sneeze voluntarily, nor can a sneeze be always successfully prevented. One is sometimes able to inhibit the reflex by making pressure upon the terminal branches of the anterior nasal nerve, more especially the mesial ones at the root of the septum.

A given stimulus insufficient to produce sneezing, may merely create a desire to do so. Under these circumstances it is often possible to precipitate the sneezing by superposing another stimulus even one of another nature. Looking quickly into a bright light is sometimes sufficient. The author has also observed a subject in whom sneezing could be precipitated by irritating a point on the scalp near the frontal hair-line.

8. Vail, Harris H.: Vidian Neuralgia. Ann. of Otol., Rhin. and Laryng., 41:837 Sept.), 1932.

The secondary reactions accompanying the act of sneezing exemplify a reflex arc originating in afferent somatic neurons and being completed through both efferent somatic and sympathetic neurons.

Reflexes from the nose set up by any type of irritation there probably communicate with the vascular apparatus of the intracranial membranes and may produce headache. The local nasal application of vaso-contrictors sometimes serves to control them. Further evidence of such relationship is found in the increased vascularity of the middle turbinate, the exaggeration of the naso-facial reflex, the presence of Ewing's sign, and the relief of headache by cocainization of the nasal membrane.[9]

MIGRAINE. Migraine has been laid at the door of the autonomic system and its evil genius, allergy. Gittins introduces the element of heredity: "Migraine and similar familial allergic or vasomotor disturbances of the brain, meninges, ganglions, nerve sheathes and other bodily structures are common and probably will continue to be so as long as hereditary characteristics are perpetuated by intermarriage without thought to eugenic selection. Reduction in the numbers and severity of the symptoms and in the numbers of prospective victims is probably more of a social than a medical problem."[10]

He makes this statement in concluding a dissertation aimed against the prevailing stand that "appendixes, gall-bladders and pelvic organs" and such should all be sacrificed before the quest for the source of the headache comes to an end.

9. Buzoianu, G.: Observations cliniques sur la cephalee rhinogene. Arch. internat. de neurol., 56:229 (May-June), 1937.

10. Gittins, T. Roy: Headache from Pathological Changes in the Nose or Other Causes. Arch. Otolaryng., 30:589, 1939.

In respect to many individuals his point is well taken. To regard pain *per se* as a hereditary factor, however, flies in the face of experience. It is more likely that what is actually inherited is a diseased or defective vascular system deserving more than a grimace at the patient's forebears.

SLUDER'S "LOWER HALF" HEADACHE. Much has been written about the syndrome described by Sluder as "lower-half headache," and frequently referred to as Sluder's syndrome. Sluder's own description follows:

"The patient presenting all the features will tell of a coryza of lesser or greater severity—sometimes astonishingly slight and often forgotten, or, it may have produced a post-ethmoidal-sphenoidal empyema. (It has been my observation that many times patients are unconscious of coryzas, but still examination shows that an inflamed membrane is the cause of headache, usually sphenoidal.) A short time later, pain began at the root of the nose, in and about the eye, the upper jaw and teeth, sometimes also the lower jaw and teeth, and extended backward to the temple and about the zygoma to the ear, causing earache; emphasized at the mastoid, but always *severest at a point 5 cm. back* of that (which is almost always quite sensitive to pressure); thence reaching backward by the way of the occiput and neck, it may extend to the shoulder blade and shoulder (less often to the axilla and breast), and in severe attacks to the arm, forearm, hand, and even the finger tips. This is the most frequent picture, but at times there may be also a sense of "stiff" or "aching" throat; or of pain (oftener itching) in the hard palate; or pain inside the nasal fossae; or a feeling that the teeth are "too long"; or a perverse (metallic) sense of taste (parageusia) (rare) or scotoma scintillans (rare) or salivation

(rare). Itching of the shoulders and upper extremity has been observed. The sense of taste is slightly less acute over the anterior two-thirds of the tongue on the affected side. Rarely, in the beginning or at the height of the attack it is slightly more acute. The arch of the soft palate is higher on the affected side; the uvula and dimple which forms above it on gagging are deflected to the well side. A slight blunting of sensation is found in the nose and throat as far down as the tonsil on the affected side. There may be a sense of stuffy ears, which are easily inflated with but short relief. I have construed these as tubes which are not opened normally by the levator palati; and that this happens because the motor function from the ganglion is lessened at the time of the attack of pain. As the pain subsides this symptom disappears. Mild cases are described as a sense of tension in the face and stiffness or "rheumatism" in the shoulder and neck. A great degree of soreness or stiffness may remain in the neck and shoulder after the pain of a severe attack has been stopped by treatment, either by cocainization of the nasal ganglion or anodynes internally. There are numerous texts in the literature dealing extensively with stiff and sore neck in which the argument is made that they are myalgia or neuralgia or sternocleidomastoid rheumatism. I believe these cases to be primarily nasal ganglion neuralgia. At the time of description the other parts of the picture were for the most part no longer present.

"The above described picture is sometimes supplemented by a sympathetic syndrome very wide in its distribution and wondrously complex, a prominent part being vasomotor and secretory phenomena. And sometimes it happens that these are the only symptoms of disturbance in the nasal ganglion.

I think, however, that the sympathetic syndrome occurs less often than the painful syndrome. But a sharp division is often impossible because the sympathetic syndrome is often mixed with the neuralgic syndrome. They may alternate in the same patient. The same etiology is found."[11]

Various explanations have been brought forward to account for the symptom. Evidence shows that the pain is due to vasomotor changes in the affected areas, the result of reflexes set up by irritation in the region of the sphenopalatine ganglion. The immediate cause of the pain is an ischemia resulting from such reflex impulses. The nervous pathways are thought by Larsell and his associates to be the nasal and palatal branches of the sphenopalatine ganglion, the great superficial petrosal nerve, the connections within the medulla oblongata with the reticulo-spinal tract and through those the segmental autonomic nerves in the lower cervical segments of the cord which supply the vasomotor innervation of the arteries of the regions involved in the lower half headache.

The evidence rests upon a series of convincing experiments on animals.[12]

The pains produced in various parts of the head by lesions of the mucous membranes of the nose and sinuses, as well as certain attendant pains sometimes present in the neck, the shoulder and the upper extremities, exhibit the common characteristics associated with referred pains. Kuntz, who has given special attention to the connections of the spheno-palatine ganglion, points out that since afferent exponents of the upper

11. Sluder, Greenfield: Nasal Neurology Headaches and Eye Disorders. C. V. Mosby Co., 1927, p. 93.

12. Larsell, Olof, Barnes, J. F. and Fenton, Ralph: Relation of Irritation in Region of Paranasal Sinuses to Certain Vasomotor Changes: An Experimental Study. Arch. Otolaryng., 27:266 (Mar.). 1938.

thoracic nerves traverse the plexuses on the common and internal carotid arteries to reach the nasal membranes, the pains may be regarded as referred, in conformity with Head's theory of the localization of referred pain. Direct pain impulses probably have their origin in the pain receptors in the peripheral area in which the pain is localized. The stimulation of these receptors is caused by the reflex responses characteristic of the production of referred pain probably through the accumulation of metabolic waste products or the liberation of a stimulating chemical substance. According to this author, impulses arising at the site of a lesion in the nasal mucosa, reach the spinal cord through afferent components of the upper thoracic nerves, pass thence to the corresponding ganglia of the sympathetic trunks, through preganglionic neurons, and are conducted to the periphery through sympathetic neurons. Here the pain receptors are stimulated, impulses once more reach the spinal cord through afferent components of the corresponding spinal nerves, travel upward through the spino-thalamic tract on the contralateral side.[13]

REGULATORY FUNCTION OF INSPIRED AIR. Stimulation by the inspired air plays some part in the regulation of patency through the autonomic system. The blood vessels reaching the nasal cavity from the pterygoid fossa are innervated almost entirely by branches of the spheno-palatine ganglion. It is a common clinical observation that once even a small air passage through an obstructed nose has been established, breathing soon follows without further manipulation through an increase in vascular tone and the depletion of the erectile system.

13. Kuntz, A.: Pathways Involved in Pains of Nasal and Paranasal Origin Referred to the Lower Cervical and Upper Thoracic Segments and the Upper Extremity, Ann. of Otol, Rhin. and Laryng., 45:394 (June), 1936.

Concerning the regulation of the erectile tissue Schaeffer has this to say: "The control of the nasal congestion and glandular activity are not under the power of the will, since unstriped or pale muscle and glands are involved. It is well known that the central processes of the cell bodies of the sympathetic afferent neurons synapse with either somatic or sympathetic efferent or motor neurons within the central nervous system in the completion of reflex arcs. Experimental evidence tends also to show that afferent somatic neurons, in addition to completing reflex arcs with efferent somatic neurons, participate in the formation of reflex arcs in which the efferents are of the sympathetic type. It is therefore possible that an impulse from the nasal cavity meant primarily to bring about reflexly a pure motor response of striated muscles results in a vasomotor phenomenon as well, *e.g.*, turgescence of the erectile tissues of the nose."

He makes this statement as part of a discussion on the mechanism of sneezing, but the arcs which he describes undoubtedly participate in the less violent reactions.

He points out also that though the turgescence and depletion of the nasal mucosa is commonly a simple reflex phenomenon, the erectile tissue of the nose is readily influenced by psychic states, indicating a connection between the vasomotor centers and the cerebral cortex.

Stimulation of the mucosa of the nose, pharynx and larynx of the rabbit with certain irritative vapors reflexly inhibits the action of the heart. Accompanying the slowing of the pulse, the arterial pressure declines in unanesthetized or lightly anesthetized animals. This decline may quickly reach a level while the pulse remains slow, finally increasing above the

original pressure as the pulse returns to the normal rate. This is not invariable. The pressure sometimes remains low, reaching the original level only as the pulse reaches the original frequency.

Tactile stimuli in the larynx or the nose may have similar effects, as may faradic stimuli applied to the nerves supplying the mucosa. In the latter case, stimulation of the branches to the nasal mucosa and the skin of the snout excites relatively less cardiac inhibition and greater rise in pressure.

Harris[14] finds that the cardio-vascular reflex system of the normal human individual is quite insensitive to nasal stimulation, but that in certain pathological states this instability is significantly increased. In this he concurs with Killian[15] who pointed out many years ago that severe cardiac reflex responses to procedures upon the human nose occur only in individuals in whom the irritability of the trigeminus is much above average.

These reflex responses may reach dangerous proportions and are occasionally fatal. Loeb[16] reports six cases of death following puncture of the naso-maxillary wall with irrigation of the maxillary sinus. He mentions 16 previously published by Gording and Grove.

Section of the cervical sympathetic ganglion is followed by trophic disturbances in the nasal mucosa, characterized by shrinking, increase in round cells and the proliferation of con-

14. Harris, A. Sidney: Cardio-Inhibitory and Vasomotor Reflexes from the Nose and Throat. Ann. of Otol., Rhin. and Laryng., 48:311 (June), 1939.
15. Killian, G.: Zur Lehre von den nasalen Reflexneurosen. Deutsch. Med. Woch., 36:1868, 1910.
16. Loeb, H. W.: Further Studies of Fatalities Following Operation on the Nose and Throat. Trans. Am. Laryng., Rhin. and Otol. Soc., 1923, p. 226.

nective tissue. Neither the respiratory nor the olfactory epithelium is affected by the section nor are the vascular or bony structures.[17]

Some evidence is presented by Kerekes[18] that pressure changes in the sinuses, at least in the maxillary sinus of the human and the frontal sinus of the dog, have a reflex influence upon the thoracic respiratory activity.

Sercer[19] has attempted to show that a reflex connection exists between each of the nasal fossae and the corresponding side of the chest. This connection is said to be for the purpose of controlling the volume of inspired air.

There is also some evidence that the reflex may operate conversely as a thoracic stimulant, but neither view has received much support at this writing.

17. Ide, H.: Ueber die durch Halssympathektomie erzeugten Veränderungen in den Nasenhöhlen des Kaninchens. Ausz. a. Otol. (Tokyo), 40:12, 1934.

18. Kerekes, Georg: Nasennebenhöhlen und Atemmechanismus. Acta Oto-Laryng., Vol. XXI. Fasc. 4, 1934.

19. Sercer, A.: Acta Oto-laryngol., XIV., fasc. 1-2 (Trans. of 3rd Reunion of Coll. of O. R. L. 1929.

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CHAPTER XIX

CLIMATE, ENVIRONMENT AND OTHER EXTRINSIC INFLUENCES

HIPPOCRATES ON CLIMATE—EFFECT OF CLIMATE ON FUNCTION—EFFECTS OF CHILLING—CLASSICAL EXPERIMENTS OF MUDD, GOLDMAN AND GRANT—"LEONARD *HILL PHENOMENON"* — *SWIMMING* — GENERAL CONSIDERATIONS—INDUSTRIAL DUSTS AND TEMPERATURES—BODY STATUS—DIET — ENDOCRINE GLANDS — GENERATIVE SYSTEMS AND THE NOSE.

For as many centuries as the records of man exist the climate has been credited with or blamed for, his current state of health. Many of the Greek temples were health resorts devoted to the physiological virtues of the sun and the atmosphere, and no doubt the travel bureaus of 300 B. C. displayed prominently a little brochure by Hippocrates called "Airs, Waters and Places."[1]

Patients today commonly attribute their colds to the weather, irrespective of the fact that the weather may have been flawless for weeks.

Specialists having tried everything else and failed, advise a change of climate which, if it accomplishes nothing else, removes the complaining one from sight. It happens often enough that a change of location, accompanied by the incidental change in diet and a much needed rest, achieves the

1. Rochester, DeLancey: Climatology as Practiced by Hippocrates. Trans. Amer. Climat. and Clin. Assn., Vol. 28, 1912.

miraculous result so that climate still maintains its high place among the panaceas.

EFFECT OF CLIMATE ON FUNCTION. In general it may be said that an unvarying climate, hot or cold, is more conducive to nasal health than one characterized by sudden changes of temperature and humidity. Probably no climate is solely responsible for pathological changes in the mucous membrane with the exception of the deserts in which heat is excessive and the humidity nil. Dwellers in the polar regions are singularly free from infections, because of the absence of bacteria. The nasal functions are not impeded by the cold. The epidemics which follow the visit of a ship may be attributed to the lack of immunity in the native rather than to the failure of the mucosa to protect him. This was amply demonstrated by the peculiar susceptibility of the soldiers from the rural districts to respiratory infection in the epidemics accompanying the first World War.

It is common experience that patients moving to a new climate are free of their usual infections for a time but these are only temporarily held in abeyance and later reappear in their former intensity.

So far as the infected sinus is concerned change of climate alone does not commonly bring the desired result. Even in those fortunate locations where the sunshine is said to spend the winter, we are told by the focal rhinologists that patients with chronic sinus infections experience little improvement. But one must distinguish between the effects of climate upon infections already established and its prospective influence upon the physiological processes of the nose.

Apart from conditions attendant upon living in any of the large cities of the temperate zone, the nasal mucosa can adapt itself quite readily to its environment. "Temperate" is a misnomer. Far from being neither extremely hot nor cold, the temperate zone is both, the changes often following one another in rapid succession. The nasal mucosa possesses great facility for adapting itself to prolonged heat and cold, as does the rest of the body. But sudden changes in skin temperature have a profound effect upon the vasomotor reactions of the nasal mucosa, and bring about conditions on its surface which predispose to infection.

In congested places, particularly halls and theaters in which the atmosphere is moist and warm, the membranes of the upper respiratory tract swell, become "logged with tissue lymph"[2], covered with a viscid secretion. The combination of the droplet infection usually present in such places and the subsequent chilling of the individual is of the greatest importance in the etiology of nose and throat infections.

EFFECTS OF CHILLING. For our understanding of the effects of chilling of the body surfaces upon the nasal mucosa we are indebted largely to the classical experiments of Mudd, Goldman and Grant performed in the laboratory and of H. Marshall Taylor upon swimmers.

EXPERIMENTS OF MUDD, GOLDMAN AND GRANT. Mudd, et al., placed the subject in a cool room, 18° C., unclothed but warmly wrapped in blankets. These could be suddenly removed without any effort or change in position on the part of the subject which could introduce errors.

2. Hill, L. and Muecke, F. F.: Colds in the Head, etc. Lancet, London, 1913.

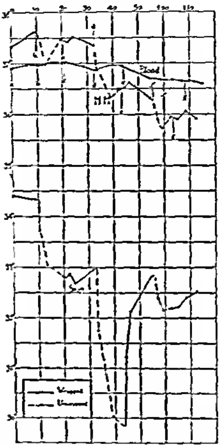

Fig. 81. Composite graph. Effects of chilling body surface. Record of Blood, Skin and Mucosal Temperatures. a, wrapped; b, unwrapped; c, wrapped; d, unwrapped, fan on back; e, fan off, wrapped; f, unwrapped, cold wet towels to back; g, dried, wrapped.

Reproduced from Mudd, S., and Grant, S. B.: Reactions to Chilling of the Body Surface. Jour. Med. Res., 40:53, 1919. By kind permission.

Applicators consisting of thermopiles designed for the experiment were applied to the mucosa of the nose or pharynx with the mouth propped open. Temperature changes in these locations, which accompanied chilling of the skin, were noted.

This chilling was effected by removing wraps and applying cold wet towels, or directing an electric fan to the subject's back.

The pharyngeal mucosa, warmed by circulating blood loses heat in three ways: by radiation through the open mouth, by inhalation of cool air and by conduction down a thermal gradient established along the air of the mouth and the metal of the applicator to the cold room outside.

Experimental conditions were maintained at a constant, so that the variations of temperature in the nose and the pharynx indicated changes in the vascular status of the area, a fall in temperature indicating vasoconstriction, a rise vasodilatation.

In the nasopharynx temperature variations closely resembled those in the oropharynx. Chilling of the skin resulted in a temperature drop of 1-2° C. Recovery, indicated by a return to the original temperature, was slow, sometimes requiring one-half hour after rewrapping the subject. Temperatures were often lower than the original level for even longer periods. In the nasal cavity the variations were shown to be similar in kind, but greater in degree, temperature reduction of 6° C. and more being the rule. With warming, recovery was prompt in this region, but as before it usually stopped somewhat short of the control level. Sometimes it rose above it.

This contrast between the behavior of the nasal mucosa and that of the pharynx is characteristic of the vascular supply and control of the two regions.

As compared to the skin of the forehead, the vasoconstrictor reflex in both nose and pharynx was found to have a low threshold. Merely unwrapping the subject in the cold room (14-18 C.) often produced vasoconstriction of the mucosa but not of the skin.

It is curious and worthy of some experimental attention that the profuse clear nasal discharge resulting from the irritation of the thermopiles upon the mucosa was not noticeably diminished by the reduction in the blood supply which occurred in response to the chilling of the skin.

The accompanying graph, a composite of the graphs from seven experiments of these authors, is interesting not only for the fact that the temperature changes actually exceed the changes produced in the skin, but also that it substantiates the observations recorded in a previous chapter that the nasal temperatures are normally about 33° to 34° C. All the reports show an initial rise in the temperature of the nasal mucosa when the thermopile is inserted, presumably the result of hyperemia following mechanical irritation.

"Leonard Hill Phenomenon." In 1931 Sir Leonard Hill reported what has since been known as the "Leonard Hill phenomenon," namely, that "rays from a dull red or dark source of heat falling on the skin of the face or body, excite reflexly a congestion of the mucous membrane which narrows the airway. Cooling the irradiated part, or face, by means of a fan or by approximation of a cold surface, prevents the reflex effect."

He adds also that "rays from a bright red source give a sufficiency of red or short red rays to antagonize the action of the long infra-red rays."

He attributes the stuffy effect of closed rooms to the reflex action of long infra-red rays.[3]

Winslow, Greenburg and Herrington made experiments to test the accuracy of these statements. They found that nasal obstruction could be produced "with reasonable certainty and constancy" by exposure of the skin to a dark glow radiant heater, immersion of the arm in hot water or exposure to a high atmospheric temperature.

On the other hand, there was an increase in patency following exposure to cold. They found further that adding light rays of shorter wave-length to those of the "dark glow" band further increased the congestion. It was not apparent that any particular antagonistic influence was associated with light rays of definite wave length.[4]

They have the impression that these reactions are slight in normal subjects, but more pronounced, at least more easily demonstrable, in patients whose nasal passages are somewhat obstructed by deviated septa or other nasal abnormalities.

Dufton and Bedford[5] came to the same conclusion, but gave it as their opinion that the nasal obstruction is a phenomenon consequent upon the application of heat and is not the peculiar effect of any specific electro-magnetic wave lengths.

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3. Hill, Sir Leonard: Proc. of the Physiological Soc., Nov. 14, 1931. Jour. of Physiol., 74:1.
4. Winslow, C. E. A., Greenburg, Leonard, and Herrington, L. P.: The Influence of Heat and Light upon Nasal Obstruction. Am. J. Hygiene, 20:195 (July), 1934.
5. Dufton, A. F. and Bedford, T.: Nose-Opening Rays. Am. Jour. of Hygiene, 23:476.

SWIMMING. Hand in hand with these researches go those of Taylor[6] and his associates who have studied the changes occurring in swimmers following prolonged submersion in cold water. They have also given minute attention to the damages wrought upon the ears and the respiratory tract through improper swimming technique, but at present we are concerned only with the physiological responses, and will confine our attention to these.

The human organism cannot long maintain its physiological processes when the temperature departs from its normal level.

Submersion in water, whose heat conductivity is 27 times that of air, is especially deleterious to man because he has no effective compensating mechanism for heat maintenance under such conditions.

Man's radiation of heat after 15 to 20 minutes' immersion in water of 21° C. may be as high as five times the normal rate. Temperatures of children swimming in an indoor pool (temp. 22.8° C.) for 45 minutes were reduced between 0 and 2° C. Eight adults swimming in ocean water at 20.3° C. suffered an average reduction in rectal temperature of 2.2° C.

Taylor emphasizes the need of exercise during the period of chilling to compensate in a measure for the surface vasoconstriction.

GENERAL CONSIDERATIONS. Wood,[7] in discussing the climate best suited to recovery from nasal maladies, voices

6. Taylor, H. M.: Sinusitis and Swimming. J. A. M. A., 85:7 (July 4), 1925.
Taylor, H. M. and Dyreforth, L. V.: Chilling of the Body Surfaces. J. A. M. A., 111:7744 (Nov. 5), 1938.
7. Wood, L. E.: Discussion of "Climate and the Upper Respiratory System" by Charlton, C. C. Trans. Am. Laryng., Rhin. and Otol. Soc., 1937, p. 13.

an opinion based upon personal experience that "air is beneficial in proportion to the degree to which it approaches the physiological ideal . . . The function of the nose is to warm, moisten and filter the inspired air, always delivering the same kind of air to the trachea regardless of what it takes in . . . This air [in the climate under discussion] already conformed to the physiologically ideal standards; it was already warm, it was already moistened, it was already pure. There was nothing for the nose to do. In others words there could be a rapid, spontaneous recovery because the nose was in a state of physiological rest."

This states the case clearly, up to a point, for those conditions amenable to rest cures. But surely the point must be relative for the lung requires air at 35° C. (95° F.) and a humidity of some 85%—which would constitute a fairly uncomfortable climate.

On principle, however, the same requirements apply to living and sleeping quarters. One has never discovered any physiological basis for exposing the respiratory tract to normal room temperatures by day and to zero temperatures by night.

Requirements for artificial air-conditioning have been discussed in another place.

It is evident that certain fundamental differences exist between noses which have throughout their lifetime breathed humid air and those which have inhabited the arid regions. These are acquired differences, to be sure, and do not long persist when the individual changes his residence from one climate to the other.

They are to be reckoned with in treatment. Thus certain nasal operations which would be followed by uncomfortable

and sometimes painful drying in the southwestern United States, may be successfully employed in humid England and patients with extensive nasal excavations may be comfortable in New Orleans and miserable in Duluth.

INDUSTRIAL DUSTS AND TEMPERATURES. Industrial dusts and temperatures have some effect upon the nasal mucosa and its vascular supply.

The dusts react only through some specific physical or chemical property peculiar to them, for inert dusts even in large amounts are carried off without any disturbance of the membrane.

Certain dusts are merely drying in their action: lycopodium, talcum, face powders. Others are chemically irritating such as the industrial alkalis and astringents. Still others act through the specific sensitivity of the individual to them (allergy): flour, pollens, animal emanations, carpet dust.

In the same way heat may also affect the membranes; those of bakers and stokers show a characteristic redness and engorgement which may go on for years without resulting in hyperplasia.

Tobacco smoking may result in an ischemia or a redness, depending upon the nature of the action, whether it be pharmacological or merely irritative.

City smoke so alters the nasal membranes that it is difficult to characterize any given mucosa in the adult as "normal." Those who contend that no "normal" membrane exists in the adult city dweller have been answered with the definition that whatever prevails is "normal" and that "normal" adult noses are therefore characterized by a certain amount of

hyperplasia and fibrosis. This is merely a war of words. The fact remains that a loss of physiological function often accompanies such changes—and often does not.

While these effects come properly under the heading of pathology, there are borderline conditions of vasodilatation which may alter the functioning of the mucosa without actually producing any pathological alterations in the membranes.

BODY STATUS. Every phenomenon pertaining to living things in health and disease is the manifestation of some immediate physical or chemical change.

The changes which take place in the nose are often only the reflection of general bodily vegetative phenomena upon which its functional status at any moment may be directly dependent.

Thus atrophy, plethora, pallor or any other state which may characterize the nose on examination, may have no basis there. One will not find an individual with sunken cheeks, wasted neck and scrawny hands to have a pink, healthy and well-nourished set of turbinates, nor should one then expect any demonstrable results to follow purely nasal treatments in such cases.

This is not the place for the discussion of diseases elsewhere in the body which may be reflected in the nose, but there exist certain physiological variations of nutrition and environment which modify the functional effectiveness of the nose and merit some attention.

DIET. To the so-called "refined carbohydrates," bleached flour and bleached sugar and the foods made from them, including bread, cake and pastry, ice cream and candies, are

sometimes attributed the nutritional disturbances responsible for the common cold and the chronic sinus disease. Seaver points out that carbohydrates in this form increase the normal vitamin B requirement.[8]

The impression is prevalent among the laity that there are certain foods, notably milk, which "make mucus," and that these must be avoided to prevent "postnasal drip," another recent lay discovery.

This notion probably has its foundation in the nasal allergies, and is suggested by specific sensitivities to milk and other foods.

The elimination diets and the therapeutic diets resorted to in the allergies make up no small part of the causes for deficiency reactions in the nose.

Vitamin A. The cell changes which take place on diets deficient in vitamin A are prominently present in the respiratory mucosa.

In experimental animals (rats) the epithelium of nose, larynx, trachea and bronchi are affected.[9]

In a small group of children who had suffered from A-avitaminosis, similar changes were found at autopsy.[10]

It should be understood that susceptibility to infection occasioned by such changes in the mucosa is seen only in persons who are subsisting on diets patently deficient in Vitamin A or in those whose body vitamin reserves have been depleted.

8. Seaver, Edwin P. Jr.: Chronic Infections, Nasal Sinusitis and Refined Carbohydrates in the Food Selection. Trans. Amer. Laryng., Rhin. and Otol. Soc., 1938, p. 302.

9. Wolbach, S. B. and Howe, P. R.: Tissue Changes Following Deprivation of Fat-soluble A-Vitamin. Jour. Exper. Med., 42:753, 1925.

10. Blackfan, K. D. and Wolbach, S. B.: Vitamin A Deficiency in Infants. J. Pediatrics, 3 679, 1933.

There is no evidence that this vitamin is a specific against colds and other upper respiratory infections, nor that excessive amounts of the substance have any effect beyond that accomplished by the minimum body requirement.

Other than this, the vitamins appear at the present writing to influence the physiology of the nose only indirectly by conserving the health of the individual.

ENDOCRINE GLANDS. Nasal infections may have deleterious effects upon the thyroid, the pancreas, the parathyroid and other ductless glands. In general these effects lie in the domain of pathology and do not properly belong in this discussion. There are occasional instances in which the physiological processes of the nasal membrane are influenced by derangements of these glands.

Circulatory changes evidenced chiefly by pallor are to be found in the nasal mucosa in the presence of thyroid insufficiency. Epistaxis occurring at puberty has been associated with the glandular changes of adolescence. The researches of Mortimer, Wright and Collip[11] with estrogenic substances confirm this.

The various hormones of the anterior and posterior lobes of the pituitary gland doubtless have their effect upon nasal development in common with their influence in other locations, but the evidence is still inconclusive.[12]

Other nasal abnormalities attributable to endocrine dysfunction are: increased vascularity of the mucosa in hyperthyroid-

11. Mortimer, H., Wright, R. P., and Collip, J. B.: The Effect of Estrogenic Hormones on the Nasal Mucosa, Their Role in Naso-sexual Relationship; and Their Significance in Clinical Rhinology. Canad M. A. J., 35:615-621 (Dec.), 1936.

12. Cody, Claude C.: The Relation of Endocrine Dysfunction to Otolaryngology. Trans. Amer Laryng., Rhin. and Otol. Soc., 1937, p. 331.

ism; malformation and rhinorrhea in pituitary disorders; hay fever and vasomotor rhinitis in parathyroid or adrenal hypofunction.[13]

The nasal secretions may be profoundly altered by certain endocrine imbalances. Castration results in atrophy of the nasal glands and their action is inhibited by the hormones of the hypophysis and the thyroid.[14]

GENERATIVE SYSTEMS AND THE NOSE. The relationship between the generative systems and the nasal mucosa has long been known but is, even at the present time, not understood. The effects of the olfactory sense upon sexual phenomena have already been noted. The nasal obstruction and epistaxis which accompany menstruation and pregnancy are common experience. In 1912 Seifert[15] found 300 essays on the subject in the literature.

Many investigators[16, 17] have demonstrated the influences of stimulation or destruction of nasal tissues upon the genital organs and functions, and not a few have permitted themselves to be carried into the realms of speculation.[18]

All manner of menstrual disturbances have been said to have been relieved by stimulation, cocainization and cauterization

13. Wolfe, quoted by Anthony, D. H. in a discussion. Trans Amer. Laryng., Rhin. and Otol. Soc., 1937, p. 339.

14. Chavanne, L.: Nasal Secretion and Endocrine Glands. Ann. d'oto-laryng. (May), 1937, p. 401.

15. Seifert, E. H. E.: Kritische Studie zur Lehre vom Zusammenhang zwischen Nase und Geschlectsorganen. Würzburg, Curt Kabitzsch, 1912.

16. Koblanch, and Roeder, H.: Tierversuche über Beeinflüssung des sexual Systems durch nasale Eingriffe. Berl. klin. Wchnschr., 49:1893, 1912.

17. Nemours, P. R.: Effects of Experimental Bilateral Turbinectomy on the Development of the Testes in the Rabbit. Arch. Otolaryng., 22:626 (Nov.), 1935.

18. Fliess, Wilhelm: Die Beziehungen zwischen Nase und weiblichen Geschlechtsorganen. 1897.

of precisely the right point in the nose, but the point varies. Probably the changes in the nose accompanying genital aberrations are more frequently their effect than their cause.

The nasal mucosa in many women becomes hyperemic and swollen during menstruation and pregnancy, sometimes to the point of epistaxis in either condition. It is not uncommon for edema and even polyposis to recur with each succeeding pregnancy. At such times, also, sufferers from atrophic rhinitis find relief from their symptoms. Conversely, nasal atrophy has followed castration in monkeys, which could be counteracted by the injection of estrogenic substances.[19]

In the rat pseudo-pregnancy can often (54%) be induced by the intranasal application of silver nitrate.[20] An irritant (mustard oil) applied to the nose does not produce the reaction. A depressant (nupercaine) duplicates the effect of the silver nitrate.

That a nervous element, apart from the olfactory innervation, is involved in this disturbance in the estrus cycle of the rat has been experimentally proven by resecting the sphenopalatine ganglion and the olfactory bulb, respectively.

The phenomenon of pseudo-pregnancy consists of a prolonged luteal phase of the estrus cycle.

What the actual connection may be between the nasal nerves and the gonads is not known, but it has been suggested in view of the close relationship of the vidian nerve to the

19. Mortimer, H., Wright, R. P. and Collip, J. B.: Effect of Administration of Estrogenic Hormones on the Nasal Mucosa of Monkey (Macaca Mulatta). Can. M. A. J., 35:503, 1936.

20. Rosen, E., and Shelesnyak, M. C: Nasogenital Relationships I. Proc. Soc. Exper. Biol and Med., 36:832, 1937.

hypophysis in the rat, that the sphenopalatine ganglion may have an influence upon the function of that gland.[21]

21. Rosen, S., Shelesnyak, M. C., Zacharias, L. R.: Naso-Genital Relationships II. Endocrinology, 27:463, 1940.

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CHAPTER XX

CLINICAL APPLICATIONS — NASAL TREATMENT

EVALUATION OF SOURCES—ANIMAL EXPERIMENTATION —FIVE MAJOR NASAL FUNCTIONS—SMELL—HEATING, HUMIDIFICATION, FILTRATION—SELF-CLEANSING—THE COMMON COLD—TREATMENT OF ACUTE INFECTIONS—ACUTE SINUSITIS—SUBACUTE AND CHRONIC SINUSITIS—COMPARISON OF DRUGS—OILS—METHODS OF MEDICATION—ISOTONICITY—MAINTENANCE OF AIR-EXCHANGE —SIPHONAGE — RIGIDITY — LOCAL IMMUNIZATION—SHORT WAVE DIATHERMY—CLINICAL ESTIMATION OF CILIARY ACTIVITY.

In the preceding chapters the author has attempted to collect what is known of the basic physiological processes of the nose and to marshal them into some semblance of coherence and order. Most of what has been set down is well grounded in research and experience; some of it is not.

It is now our task to evaluate present therapeutic measures in the light of this knowledge, to discard what is incompatible with it and to devise more rational methods to replace what we discard.

This must be done without prejudice. The only thing which elevates our judgment above that of the laity is knowledge. If we lose sight of this knowledge and abandon ourselves to the fetters of custom and the glamor of passing fads then we have missed the whole purpose of our training.

The patient may be forgiven for his fantastic ideas of therapeutics, but not the doctor. To him is available accurate basic knowledge and his alone is the stability born of experience.

The patient derives his vagaries from the magazines he reads; unless the doctor scans the medical literature with greater discernment, he will fall into the same trap. He must select his authors and his sources.

EXPERIMENTATION. He must guard against accepting or discarding a procedure merely because it has some certain effect upon an animal. For example, it has been shown that repeated irrigation for 28 days of a healthy rabbit's sinuses, even with physiological sodium chlorid solution, produces a cloudy swelling of the epithelium. This may be important but it should not condemn *per se* the use of saline irrigations. It is conceivable that a transient cloudy swelling may be preferable to something else which yields to the irrigation. Six weeks' confinement in bed will incapacitate the strongest man, yet it is indicated for typhoid fever or a fractured femur. Besides, a slight modification may render the doubtful treatment practical; thus adding a little ephedrine to the sodium chlorid prevents the cloudy swelling.

Further, washing a rabbit's sinuses daily for 28 days is extreme and the results, whatever they may be, have no bearing on the propriety of irrigating a man's sinuses six or eight times in the same period. Administering 2 cc. of any solution to a 120 gm. rat is equivalent to giving 1,200 cc. to a 150 pound man. One should not deduce from adverse results in rats that the procedure would harm the man, unless one contemplated administering the treatment to him in comparable doses, namely a quart at a time.

When, for example, of a series of eight rabbits irrigated with a .9% sodium chlorid solution in order to test its effect on the mucosa, three died of broncho-pneumonia following the procedure then obviously there was something in the experiment which was not comparable to irrigation as customarily practiced on the human. Under these false conditions the fact that purulent sinusitis ensued in some of the survivors seems hardly worth recording.

Animal experimentation has produced more sound knowledge and saved more lives than any other type of medical investigation, which has earned for it a large measure of confidence and respect. But not all animal experimentation is sound. Scientists worthy of the name are cautious in drawing conclusions and do not apply their findings to humans until they are fully justified in doing so.

Mice, rats and fowls have been kept for generations in a constant state of alcoholic intoxication without any demonstrable deterioration. Guinea pigs, on the other hand, go to pieces under the same treatment.[1] Obviously, comparative deductions from such experiments cannot be applied to humans unless it can somehow be determined to which—rat or pig—category they belong.

If undue emphasis seems to have been placed upon this theme it is only because of the rising consciousness that rhinology is undergoing a renascence and that now is the time for all good men to do their own thinking.

In what follows it is not planned to recount the accepted medical and surgical procedures. This has been done many times over. It is intended rather to present a résumé of the

1. Wells, Huxley and Wells: The Science of Life. Doubleday, Doran & Co., 1931, p. 590.

author's own deductions based upon the physiology as he understands it.

It remains a matter of the reader's individual judgment to evaluate the physiological processes, to balance them against the emergency of the moment, and to decide in a given case which are to be conserved and which must be sacrificed—and why, and when and how.

FIVE MAJOR NASAL FUNCTIONS. Among the functions of the nose there are five to be specially guarded in the interest of the patient's health and comfort. They are smell, filtration, humidification, heating and the power of the nose to cleanse itself.

In view of the minor part which the sense of smell plays in our daily lives it might be concluded that the patient could do without it altogether, and regard his anosmia with equanimity. This is not often the case. The enjoyment of food is, after all, a fundamental pleasure and one which most humans do not relinquish lightly.

If anosmia is ever bearable the parosmias are not. The haunting odor is seldom a pleasant one. Sometimes it is merely disturbing: the patient is forever on the lookout for something burning, or he thinks he detects escaping gas.

More often the smell is musty or fetid (not to be confused with ozena), and since all food seems to be tinged with it, causes disgust and loss of appetite.

Little can be done for these conditions once established but it should be remembered that injudicious treatment in the olfactory area may be the cause, and therefore escharotics, strong astringents and kindred destructive substances should be

kept away from it. Likewise pressures, obstructions and infections should be corrected before injury to the nerve occurs.

Heating, humidification and filtration depend so closely upon the same factors that therapeutically they may be considered together. They hinge largely upon adequate circulation, a free breathing space and the integrity of the mucous glands.

While the humidifying agencies of the nose are still intact it behooves us to supply them with air which is not altogether beyond their powers in point of dryness and dust content. If the air in living quarters is heated for the comfort of the skin, it should also be moistened for the safety of the mucosa.

It is the part of the rhinologist to explain to his patients that pans of water attached to radiators are, in general, quite inadequate. One need only take a few readings with a sling psychrometer to convince himself that the average house requires as much water in an hour as such pans evaporate in a day.

A boiling teakettle may suffice for a small apartment and the air in a sickroom may be improved by allowing a hot shower in an adjoining bath to play for a few minutes several times a day. Steam condenses on cool surfaces, such as furniture and window panes, therefore if the moisture is to be kept high either it must be constantly replenished or some means must be employed to prevent condensation. (Fans or double sash.)

Inexpensive humidifiers are now on the market which agitate water and beat it into a fine spray. These are very effective. Similar contrivances are incorporated in air-conditioning equipment.

More water is required to humidify a house than one might suppose. The following data are applicable to a house of a cubical capacity of 50,000 cu. ft.:

Temperature	Rel. Humid.	Water (pounds)	Water (quarts)
70 F	40%	25.55	12.24
75 F	40%	30.40	14.57
70 F	15%	9.58	4.59
75 F	15%	11.40	5.46

From this it will be seen that with the temperature at 75° F. it requires 19 pounds of water (or 9.11 quarts), to raise the humidity from 15% where it is apt to be with the furnace operating and no humidification, to the desired 40%; with the temperature at 70° the water required is 16 pounds (or 7.65 quarts).

The amount of water which must be continuously supplied to maintain this humidity depends upon a number of factors such as condensation, absorption by textiles and other materials in the house, and the induction of outside air through chimneys, air ducts and seepage.

A most difficult problem in treatment is the maintenance of moisture and mucus in the presence of the various nasal atrophies. With an inert epithelium and a supply of mucus both scanty and defective in quality the patient is obliged to apply some artificial means of keeping his nose clean and comfortable.

In the case of atrophic rhinitis with ozena, the topical application of the female hormone has met with limited success.

Essayed at first on theoretical grounds it is thus far the only specific agent to show any effect.

In order to stimulate the glands and to supply and retain moisture in cases of rhinitis and pharyngitis sicca, and of senile atrophy of the mucosa, the author employs a solution of alcohol 5%, glycerine 3% and sodium chlorid .9% in distilled water. This gives the patient much comfort and has the advantage of being well tolerated in any amount over long periods of time. A half-dropperful is injected into each nostril, almost ad libitum. The solution has the odor of stagnant water, but the addition of a few drops of some harmless scent such as spirits eau de cologne will render it most acceptable.

The question is often raised whether it is "healthy" to sleep in a cold room, especially for patients with upper respiratory infection. This Spartan habit is declining in popularity.

It does not seem quite logical for one who has spent his waking hours breathing air at 70° to subject his air passages suddenly to a temperature of 20° for eight hours, lying quiet the while. No doubt he would complain bitterly if asked to sit on a park bench for a like period in a like temperature by day. The unnecessary loss of body heat and the risk of chilling portions of the skin which may become uncovered are the two major arguments against it. Air to be fresh need not be cold, and clinical experience suggests moderate temperatures for both sleeping and waking.

In winter a room properly humidified may be kept at a lower temperature than one in which the air is dry, without causing the occupants any sensation of chilliness. This is so because in dry air the perspiration evaporates rapidly, reducing the skin temperature.

In summer if one has been perspiring outdoors, and comes into a room which is cooled but in which the humidity is excessive, the clothes become cold and wet and uncomfortable. If the air is dry, the evaporating perspiration itself cools the skin and the actual temperature differential between indoors and outdoors need be much smaller for comfort.

Thus proper humidification effects an economy in both winter and summer conditioning.

We come now to the fifth function, namely the power of the nose to keep itself clean. Conserving this involves the maintenance of the belt conveyer (the cilia and the mucous blanket), the removal of impediments and obstructions and the supply of moisture. Most nasal treatment is concerned with it, and no plan of medication or surgical intervention can succeed without it.

Therapeutic measures must be selected first with a view to preparing a condition favorable to the growth and protection of the cilia and the production and conservation of the mucus; and second with a view to avoiding measures which will hamper, damage or destroy these agents.

The most elemental, as well as the most frequent derangement is acute infection of the upper respiratory tract including the "common cold." To attempt to outline the etiology of colds would be futile—many authorities doubt it to be a single entity—but at least one chain of prodromal symptoms can be described in terms of physiological reactions which merge only gradually with pathological ones.

THE COMMON COLD. Assume that the nose is free from structural anomalies and that the body is suddenly chilled.

There occurs an ischemia of the nasal mucosa[2]—an increase of breathing space, together with a reduced circulation, followed shortly by a congestion and partial blockade of the breathing space. The air stream now rushes through a narrowed channel incapable of properly moistening it, and causes a jet of dry air to strike the nasopharynx. This soon produces a dry spot and local stasis of ciliary activity permitting the accumulation of mucus and the growth of bacteria. These are caught and held on the sticky spot long enough to multiply there. They penetrate the cell walls themselves, not merely the intercellular spaces.[3]

Thus is brought about the familiar "burning" spot between the nose and the throat which warns the patient that he is taking cold. At this point the process is already in the tissues and spreads rapidly, not through dripping, sniffing, swallowing or any other surface agency but through the lymph spaces and vessels into the depths of the neck, and eventually into the blood stream.[4]

Just how much of the lymphatic system becomes involved before the infection is arrested depends upon the nature and virulence of the invading organism and the immune reactions of the host. The more vicious and far-reaching infections are

2. Mudd, Stuart, Grant, S. B., and Goldman, Alfred: The Etiology of Acute Inflammations of the Nose, Pharynx, and Tonsils. Ann Otol., Rhin. and Laryng., 30:1 (Mar.), 1921.—Spiesman, I. G.: Vasomotor Reactions. Tr. Chi. Laryng & Otol Soc., 1933

3. Dixon, Evelyn: Researches in Bacterial Penetration of Epithelium at the Oscar Johnson Institute.

4. LeMée, J. M., and Bouchet, M.: Mode d'elimination du lipiodol dans la methode de deplacement. Ann. d'Oto-Laryng., (Aug.), 1932, p. 919. —McMahon, B. J.: The Spread and Phagocytosis of Particulate Matter in the Nasal Mucous Membrane of the Rabbit. Tr. Am. Laryng., Rhin. & Otol. Soc., 1933; Ann. Otol., Rhin. and Laryng. (Sept.), 1933.—Mullin, W. V.: A Review of Sinus-Chest Infections. Ann. Otol., Rhin. and Laryng., 41:794 (Sept.), 1932.—Pfahler, G. E.: Lymphatic Drainage from the Maxillary Sinuses. Am. J. Roentgenol., 27:352 (March), 1932.

usually not those attended by copious pus formation, polyps and other local manifestations but rather those which produce relatively little local reaction and slip unhindered into the body fluid streams.[5]

TREATMENT OF ACUTE INFECTIONS. If all this is true it follows that little is to be gained by treating acute conditions with surface applications and gargles. The logical treatment is to re-establish even air distribution by means of the least irritating constrictors, which will not harm the cilia, and to stimulate nasal secretion to prevent dryness. Elimination of the already absorbed toxins is next in importance. The general nourishment should be maintained. This should be done by gentle and complete shrinking with ephedrine and by administering salicylates, fluids, mild cathartics if indicated, and a hot bath (whiskey is not indicated as it often produces nasal engorgement and obstruction).

The nasal glands embarrassed by disturbances in the circulation, by obstruction of their ducts and in those areas which remain exposed to the air-streams by the excessive demands made upon them, require assistance in the form of moisture artificially supplied. This is best accomplished by steam inhalations. Douches are contraindicated at this stage since they only interfere with the re-establishment of physiological order and what surface moisture they contribute is quickly evaporated.

Much benefit may be derived however from heat applied to the pharynx either by hot douches, or, more simply, by holding hot water in the throat and swallowing it slowly. The result is a diminution of the lymph-vascular congestion, with relief.

5. Menkin, Faly: A Factor in the Mechanism of Invasiveness by Pyogenic Bacteria. Tr. Am. Path. & Bact. Soc., 1933.

The same is true of heat applied to the neck and to the body, if the discomfort extends so far. The readiest means of applying heat to these parts is to have the patient lie for 15 minutes up to his neck in a hot bath.

If these measures are adopted as soon as the postnasal burning is experienced, many colds can be aborted overnight. Antiseptics are practically useless. The disease is progressing deep in the tissues, where antiseptics, however effective, cannot penetrate. At best they may protect the original point of entrance against further invasion until the epithelium recovers.

Any remote advantage to be derived from gargles depends on mechanical cleansing and not on their antiseptic qualities. Their action persists for only an insignificant fraction of the time required to kill or even inhibit bacteria.

ACUTE SINUSITIS. Coming now to the sinuses, it is generally agreed that the management of acute sinusitis should be essentially medical, which does not mean that there is never a place for surgery, but it does mean *almost* never. This is especially true of the middle meatus, and the region of the naso-frontal duct.

Topical applications are sometimes made by such means that they are tantamount to surgery. It may be well to point out that they should have for their purpose merely the carrying of medication to a surface which cannot be reached by even gentler methods. Mechanical dilatation is not part of their function. Hoople joins in the opinion of his teachers who classify puncture and irrigation of the antrum not among the medical but among the surgical measures. It is the experience of most clinicians who have the patience and skill to employ constrictors effectively that although they may evacuate the

pus more slowly in the early stages, recovery actually takes place more quickly than when puncture is made.[6]

Acute sinusitis is commonly the extension of acute rhinitis. It partakes of the characteristics of the latter except in such respects as it is influenced by mechanical conditions. That is, it localizes, persists, and becomes dangerous only because the obliteration of the ostium through edema causes the sinus to retain noxious substances of which its epithelium could otherwise have rid it.

The procedure of choice is therefore to clear the way with minimal trauma and the least injurious vasoconstrictor. This may be ephedrine or one of the related synthetic preparations, or failing any effect from these in a reasonable period it may have to be epinephrin. What constitutes a reasonable period will depend upon the condition of the patient, and the severity of his pain. Meanwhile morphine may be required. Heat externally expedites the release of pressure and obstruction and eases the pain. Appropriate general measures should be included in the treatment.

In applying the vasoconstrictors small pledgets of cotton should be wound upon the thinnest flexible copper applicators bent to adapt them to the contours of the nose. These should not be forced into the meatus. If they cannot immediately be laid into the slit, and usually they cannot, successive applications should be made, shrinking the membrane a little at a time. The gentleness with which the applications are made is most important in hastening recovery. Wooden sticks have no place in the nose.

6. Hoople, Gordon D.: Non-Surgical Treatment of Diseases of the Nose and Pharynx. Ann. of Otol, Rhin. and Laryng. 48:73 (Mar.), 1939.

Irrigations should be avoided in the early stages of an acute us infection, as they may spread the infection. Theoretically ey are safe only after a general immunity to the invading ganism has been established. Experience shows that after ver and leucocytosis have gone fluids no longer spread in- ction in the nose. Displacement treatment may be resorted , and at this stage it will be found to be most effective. It ould not be regarded as an irrigation in the sense that it ashes out pus, but rather as a means of introducing into the uses medication which otherwise would be confined to the sal fossae alone.

SUBACUTE AND CHRONIC SINUSITIS. If the infection is st seen at a later, even *much* later, stage the problem may ll remain the same. It is now known that the membrane ing the sinuses has a tendency to recover and to rid itself infection, if not of fibrous tissue, for a much longer period an was once supposed, provided that facilities for ventilation d drainage are established and maintained, and the individual well nourished.

It is known also that the cilia function in infected sinuses can be made to do so with slight encouragement, and that e tunica has the same faculty for overcoming infection as e other tissues of the body, requiring chiefly drainage to do so.

Repeated instillations of harmless vasocontrictors in isotonic lutions at 48-hour intervals by the displacement procedure sually maintain such drainage, and have the advantage over rgical drainage of creating a minimal disturbance and inter- rence with the ostium.

It has recently been shown that cold compresses, ice bags, ot compresses, hot water bottles and electric heating pads roduce no temperature changes in the sinuses.

Following the use of the infra-red lamp and the high frequency oscillator (9000 to 12,000 kilocycles) there is a drop of about a degree in the temperature of the sinuses. Tebbutt,[7] who made these observations, lays this drop to the evaporation of the increased nasal secretion which accompanies the use of these agents. One cannot altogether accept this explanation, since evaporation is a function of surface area rather than of the total amount of fluid present and there is no evidence that the moist area is increased by the application of the heating agents.

An unhealthy nasal condition is often maintained by a single diseased sinus. It is vitally important to the success of any treatment therefore to identify this cavity, as the conditions which prevent its drainage will in all likelihood render it also inaccessible to treatment solutions, and it usually requires special attention. Time is an important factor in bringing about the desired results in such cases but less time is required than it takes for the membrane to be regenerated after removal —a matter of six weeks to three months.

The fact that a sinus remains dense to X-rays after treatment is no indication that an active disease process still persists.

Frequent irrigation of the nose and sinuses over long periods is to be avoided, as it tends to produce a bogginess of the mucosa.[8]

Comparison of Drugs. Mention should be made of the relative merits of aqueous solutions of ephedrine. From the author's own observation it would appear that for home appli-

7. Tebbutt, Harry K.: The Effect of Physical Agencies Upon the Temperature of the Nasal Sinuses. Trans. of the Amer. Laryng., Rhin. and Otol. Soc., 1935, p. 270.

8. Lillie, H. I.: Chronic Suppurative Sinusitis: A Point of View as to Treatment. Arch. Otolaryng., 21:272 (Mar.), 1935.

cation 2% of the sulphate or the hydrochlorid in a physiological sodium chlorid solution accomplishes all that can be expected of ephedrine in any form, that no other preparation of ephedrine excels it in any respect and that most of them are definitely inferior. Isotonicity need only be approximated as evaporation in the nose is rapid and the concentration of instilled solutions is quickly increased.

It is logical to select for a given purpose a drug which will upset as little as possible the normal function of the part.

On this score, one should recommend ephedrine or neosynephrin in preference to cocain or epinephrin in all cases in which its action will suffice. So far as the effect of ephedrine on cilia is concerned, it may be used in any strength up to 3% with impunity. Amphetamine is likewise harmless to cilia, as commonly employed.

If cocain is required for anesthesia, or epinephrin for ischemia, it would appear that the weakest effective solution should be chosen to insure ciliary activity immediately after operation. None of the turbinated bones examined after operations under cocain anesthesia with epinephrin showed any ciliary activity, although the adjacent sinus linings invariably did so. The fact that normal appearing cilia were present indicates that they were only recently paralyzed by the preliminary cocain and epinephrin.

General anesthesia with sodium amytal or morphin and scopolamine has apparently no effect upon the ciliary beat; even the mucosa from animals killed by an overdose of these drugs shows unimpaired activity.

Colloidal solutions having a tendency to clog the streams of mucus are to be avoided in any but the weakest concentra-

tions. Since the infectious process is beneath the epithelium, it is doubtful whether any antiseptic value which they may possess can compensate for their mechanical disadvantages.

Oily mixtures are to be avoided where ciliary streaming still functions, because they interfere not with the ciliary beat, but with its effectiveness by lying upon the mucous blanket and being propelled with great difficulty by it.

OILS. Enough has already been written regarding the shortcomings of oily preparations in the nose to make further comment covering them scarcely necessary. The practice of oiling the nose because it is dry has much the same rationale as oiling the geraniums instead of watering them. It might be simpler to oil them, or coat them with petrolatum than to fetch the watering pot or to keep the green-house moist, but the result would be as disappointing as it is in the nose.

Probably the most futile of all of the oily preparations are the various phenol and iodine drops still commonly prescribed. The phenol and iodine in this mixture are so firmly bound to the oil that they have a negligible effect upon the mucosa.

Stark[9] has shown droplets of petrolatum beneath the epithelium after injection into sinuses, and Wright,[10] stated that bacteria, refused admission by the epithelium of the tonsillar crypt could be made acceptable by coating them with butter! Thus oily solutions may actually assist in the penetration of bacteria.

Oily solutions of ephedrine have now largely disappeared from the market. The fact that in the nose, as elsewhere,

9. Stark, W. B.: The Effect of Mineral Oil and Solutions of Ephedrine on the Normal Nasal Mucous Membrane of the Rabbit. Arch. Otolaryng., 16:39 (July), 1932.

10. Wright, Jonathan: A Résumé of Some Work on Infection Through the Tonsillar Crypts. Laryngoscope, 19:321, 1909.

water mixes better with water than with oil (nasal mucus being 95% water) is only part of the story. The "plain" oily ephedrine solutions often contain an aldehyde, introduced to render the alkaloid soluble. Although some manufacturers now claim to have eliminated this irritant, the author recently saw a bleb the size of a silver dollar and half an inch thick on a patient's arm, produced by applying overnight—as a patch test—one of the popular brands of "ephedrine inhalant." This was done to investigate the cause of similar blisters of the nose and upper lip following its use. Simple aqueous solution of ephedrine produced no irritation in this patient.

In the same limbo belong also the myriad camphor-menthol-eucalyptol-pine oils, under whatever name. Fox[11] has verified the clinical experience that menthol is an irritant and without beneficial qualities, and that camphor and eucalyptol are inert. Oil of pine needles may actually increase the dryness which it was employed to combat. Apparently the only action of these oily mixtures is lubrication, which may interfere with the nasal physiology enough to be the determining factor between health and disease. If ever, it is of use only when the glandular apparatus has completely succumbed.

A truly important problem is the control of moisture of the membrane and, concomitantly, the viscosity of the mucus. Atropine is effective as a desiccant, but it impedes the flushing of the membrane, and one should not treat symptoms at the expense of the defense mechanism. Local vasoconstrictors also cause dryness, but these can be better controlled. It is curious that, unlike the ischemia produced by these substances, the vasoconstriction which follows chilling of the body surface is

11. Fox, Noah: *Effect of Camphor, Eucalyptol and Menthol on the Vascular State of the Mucous Membrane.* Arch. Otolaryng., 6:112 (Aug.), 1927.

not accompanied by a suppression of mucus but sometimes by an increase.

METHODS OF MEDICATION. The method of applying solutions to the nose is important, a fact which has been stressed chiefly by the manufacturers of various devices. Their recommendations however can scarcely be regarded as unbiased.

In the opinion of the author, the medicine dropper, abetted by gravity, is far and away the most effective instrument for the dissemination of fluids in the nose and the upper crevices of the meatuses where they are chiefly required. If the nose were well open, as it is seen in the cadaver, and in the advertisements, almost any method would suffice. But in the swollen and partly obstructed fossa to which the medication is especially directed, penetration is not easy.

When the nose is partly closed, and what breathing there is takes place through a narrow channel, sprays and vapors come in contact only with the exposed walls of the tunnel; they reach the portion of the nose which is already open and not the portion which is shut. In the case of the vasoconstrictors naturally the effect extends somewhat beyond the immediate areas of contact, but unless several successive applications are made at short intervals it does not reach the ostia—a critical shortcoming.

If on the other hand the patient is placed with his head in a dependent position, and drops are instilled into the nose they are slowly carried by gravity into the upper reaches of the fossa. In the case of the vasoconstrictors in the swollen nose, these shrink their way as they go, and as the constriction advances the fluid keeps up with it.

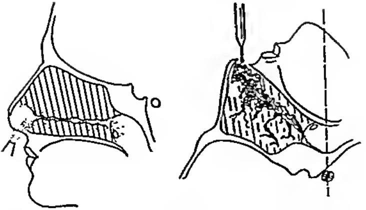

Fig. 82. Diagram showing the superiority of the dropper and the inverted position (right) over atomizers and inhalers (left) in the penetration of medication to the obstructed regions of the nasal fossa.

In the office under the direct vision of the physician sprays can of course be used, as they can be effectively directed and repeated if and where required to open all the airways.

Inhalers containing volatile constrictors have the advantage of convenience, and the added penetration permitted by the volatile medium, though they likewise reach only the exposed surfaces, and some of them still have deleterious side-effects. There is also the chance of projecting a concentrated stream of the vapor through a partly occluded nose against the pharynx or the larynx and producing dryness and hoarseness.

The author regards the various jellies and emulsions as definitely less effective than aqueous solutions of the corresponding drugs, chiefly because of their physical characteristics.

Isotonicity. It may be said in a general way that solutions to be applied to the nasal membrane are most effective and also least deleterious when administered in a medium

which closely resembles the normal nasal fluids. Such solutions as Ringer's or Locke's would be theoretically preferable, however an isotonic sodium chlorid solution suffices for practical purposes and is the vehicle of choice for whatever drugs are soluble in it.

The case of alcohol (cit. Chap. 16) illustrates this. Diluted with distilled water, it is not tolerated by the epithelium in any concentration, however weak, because the distilled water itself is inimical to the epithelium. Alcohol diluted in Ringer's solution on the other hand, is well tolerated in concentrations up to 30%.

Solutions intended to remain within the sinuses should be as nearly isotonic as practical. In the nose alone this is less important as the first breath evaporates a sizeable amount of water and promptly increases the concentration.

Solutions used for the displacement method, especially when "washing through" is done, should be colorless. Coloring materials obscure the presence of straw-colored transparent exudates which are therefore overlooked.

Chiefly in order to make them commercially acceptable and different from something else already on the market, manufacturers are prone to combine drugs to make "elegant" preparations. In this way substances are sometimes introduced which smell pleasant or feel "clean" but which, aside from contributing nothing to the mixture, render it irritating.

It is the fashion in medical advertising at present to quote extensively from the authorities. This practice is acceptable so long as the quotations are made in good faith and the sources quoted are actually authoritative, but it goes without saying that medical literature is so voluminous and authors

sometimes so irresponsible that a clever copywriter finds little difficulty in bolstering up his contentions however specious with a glittering array of exponential figures and references.

Likewise, fragmentary quotations from the authorities may by virtue of some context other than that in which they originally appeared be made to assume a meaning entirely foreign to that intended by the author quoted.

The responsible physician if he gives them any attention will examine these statements critically and take them for no more than they are worth.

Maintenance of Air Exchange. Air exchange between the nose and the sinuses is of less importance in its extent than in its simple existence. The actual air exchange is insignificant but the attendant circumstances, the open meatus, the patent ostium, and the movement of fluids are all essential. Even before any serious impediments occur, the patient is conscious of an obstruction, sometimes through an alteration in the timbre of his voice, at others through sensations of pressure or pain. Appropriate corrective measures should be taken as early as possible in order to prevent the permanent changes in the mucosa, which even much more extensive treatment will fail to efface later on.

The conservation of air currents becomes a therapeutic problem when these are unevenly distributed and either produce stasis by local drying of the mucosa, giving rise to infection, or are projected sharply against a sensitive area, giving rise to local pain or to headache.

Not unusually the patient complains of pain on the patent side and not on the obstructed one. It can be readily seen

how this occurs. Sometimes the situation is relieved by simply opening the obstructed side; sometimes it is also necessary to obstruct the overpatent side for a time by blocking the nostril with cotton and giving the mucosa an opportunity of recovering; in some cases inhalations of steam are more effective than obstruction with cotton.

SIPHONAGE. Siphoning fluids through the nose for irrigation is open to several objections. The first is that attempting to siphon through an obstructed nasal chamber will probably result in forcing some fluid into the nose under positive pressure, which is always to be avoided; in the presence of dehiscences leading to the cranial cavity or the orbit it may be dangerous. Then it has the failing, in common with other massive irrigations, of being difficult to control and of missing the more obstructed portions of the nose which it was particularly intended to free.

RIGIDITY. The clinical application of what has been said of the rigidity of the nasal framework has to do with suction, irrigation and siphoning.

Suction in the nose should be made either through a cannula for the purpose of removing secretions in the nasal chambers or through an olive tip for the gentle exhaustion of the small quantities of air necessary for displacement. It should not be used strongly in any generalized way in an attempt to empty the sinuses of secretions. This it will fail to do for the reasons already mentioned. The extent to which massive suction may be applied for displacement or any other purpose is 150 mm. Hg., at most 180 mm.

Physical circumstances which attend the pneumatization of the frontal sinus influence the continuity of the naso-frontal

luct. This pneumatization may arise either before or behind he hiatus semilunaris and may create an abrupt double turn n the duct. This presents no hindrance to the cilia in emptyng the sinus so long as the mucosa is not obstructive. But probing or cannulization is a different matter. Entering such a sinus through the nose is impossible.

Cannulization of any ostium may be practiced whenever it can be done without trauma; that is without *any* trauma.

Local Immunization. In combating certain microorganisms capable of paralyzing the cilia and penetrating the epithelium, Walsh and Cannon have found intranasal immunization of even highly susceptible animals effective.[12]

Prophylactic subcutaneous injection of vaccines against the common cold, "the cold shots" for which the laity clamor, has proven ineffective in the vast majority of cases. Walsh maintains that the procedure is irrational and advocates the local application of vaccines made from cultures obtained from numerous patients in the acute and chronic stages of upper respiratory infection.

The vaccines are applied by the patient with an atomizer each night for three weeks, and again after one week's rest for two weeks, after which they are continued for alternate bi-weekly periods from September to May.[13]

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12. Walsh, T. E. and Cannon, P. R.: Studies on Acquired Immunity in Rabbits to Intranasal Infections with Type I Pneumococcus Jour. of Immunol., Vol. 31, No. 4 (Oct.), 1936.

13. Walsh, Theodore E.: Intranasal Vaccine Spray: Its Use in Prophylaxis Against the Common Cold. Ann. of Otol., Rhin. and Laryng., 49: (Dec.), 1940.

Short Wave Diathermy. Short wave diathermy does not replace established methods and there is no unanimity of opinion as to its possible supplementary value.[14]

Whether or not local heat is produced by this method, and there is some diversity of opinion on this point also, the results are identical with those attending the application of heat and no more.

"Medical diathermy is the therapeutic use of heat generated in the body tissues by a high frequency current which has insufficient local intensity to produce temperatures high enough to destroy the tissues or impair their vitality. Such currents are applied locally by three methods: (1) conventional long wave diathermy, contact metal electrodes being used, (2) short wave diathermy with an electric field, air-spaced or insulated electrodes being used, and (3) short wave diathermy with an electromagnetic field method, a cable being used.

"In conventional or long wave diathermy the frequency of oscillation is usually from one-half to three million cycles per second. In short wave diathermy the frequency of oscillations may be from ten million to 100 million cycles a second."[15]

Clinical Estimation of Ciliary Function. The functioning of the cilia in the maxillary sinus has been clinically estimated by placing a small quantity of lipiodol—1 cc. or less—into the antrum and observing its evacuation by a series of X-ray pictures.[16]

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14. Hollender, A. R.: Short Wave Diathermy in Treatment of Nasal Sinusitis. Arch. of Otolaryng., 30:349, 1939.

15. Medical Diathermy, report of the Council on Physical Therapy. J. A. M. A., 112:2046 (May 20), 1939.

16. King, Edward: A Clinical Study of the Functioning of the Maxillary Sinus Mucosa. Ann. of Otol., Rhin. and Laryng., 44:480 (June), 1935.

Drainage as a whole, whether by ciliary action, gravity or other means can be simply determined by introducing a radiopaque oil into the sinuses by the displacement technique and observing its spontaneous evacuation in successive x-ray examinations. Two films ordinarily suffice: one made just after the introduction of the oil and another 72 hours later. The submento-vertical position is the most informative for this purpose, since the sinuses do not overlap as in the posterior-anterior positions, while the right is still easily distinguished from the left. The "normal" emptying time depends somewhat upon the viscosity of the oil but is readily determined for any given radiopaque. The 72-hour period referred to applies to a mixture of lipiodol 1 part, olive oil 3 parts[17].

The patency of the ostium is indicated by this method, as well as the thickness and general character of the membrane, the distribution of hyperplasia, and the presence of cysts.

The question arises when to operate on a sinus. The answer is based in the mind of each surgeon upon his own experience, and is colored by his training and by his conception of nasal physiology and the pathology of infectious processes.

For his own purposes the author has adopted a *rationale* which fits loosely about the following plan:

If a nasal infection proves intractable a generalized diagnostic oil instillation is made by the displacement method.

If oil fails to enter a sinus it is under suspicion.

If oil or ephedrine fails to enter a sinus after thorough shrinking of the ostium and the obstruction persists over a period

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17. Proetz, A. W.: The Displacement Method of Sinus Diagnosis and Treatment, St. Louis, 1931.

longer than might be expected from a transient edema, then operating is indicated if the symptoms demand it.

Operate also if the process threatens the patient's permanent health or safety and is advancing too rapidly to permit of leisurely study.

Operate also when more conservative measures well executed have failed *and the operation has some reasonable likelihood of success.*

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CHAPTER XXI

CLINICAL APPLICATIONS—NASAL SURGERY

VISUALIZING THE PROBLEM — CORRECTION OF AIR DISTRIBUTION — CORRECTION OF THE SEPTUM — THE TURBINATED BONES—CILIA—SINUS SURGERY—OSTIA—FOUR FUNDAMENTAL PRINCIPLES — THE ANNULAR CICATRIX — A SPHENOID OPERATION — ETHMOIDAL SINUSES—GENERAL CONSIDERATIONS.

The surgical implications arising from a survey of the nasal functions are fairly clear. Aside from the removal of tumors and the correction of cosmetic shortcomings, surgery of the nose has only two purposes: to eradicate infection and to restore physiological harmony. It is often as difficult to do the one as the other and certainly neither can be accomplished alone.

Most operations succeed in this, but experience has shown that one may be confronted from the start with the necessity of compromising between the desired result and an attainable one.

This does not mean that one is to be content with something less than the best which the situation permits but it means that he should recognize from the beginning the improbability of a complete cure in such cases and limit his operations to measures which will alleviate and not add to the patient's distress. It means that one will balance the eventualities carefully and will choose his course with a fine regard for the patient's ultimate comfort and safety.

VISUALIZING THE PROBLEM. It is quite essential to a successful outcome that the surgical program in every case be adapted to the peculiar requirements of that case. It is important also that the requirements be visualized from end to end so that surgical and therapeutic measures may become part of definite plan and not be applied unrelated and *seriatim* until 'ery does or does not ensue.

'r as the patient's ultimate health is concerned, it is assume in general that the restoration of function has a chance of eventually eradicating infection than vice

The elimination of bacteria *per se* is only part of the problem. With a fair amount of function remaining the nose has a chance of ridding itself of infection, or reducing it to a negligible minimum; but a nose, hollowed out in an attempt to eradicate infection, can never re-establish function and by that fact alone is doomed to re-infection. Often the patient is left with intractable headaches beside.

CORRECTION OF AIR DISTRIBUTION. The simplest surgical measures are those co... only applied to the redirection and redistribution of air. They come under the head of streamlining and are planned simply to spread the air as evenly as possible over the nose. They include the removal of polyps, spurs and sometimes portions of turbinated bones. When hypertrophy of the inferior concha is the trouble, that bone is not removed. The redundant portions may be trimmed effectively or grooved by means of the actual cautery. Submucous cauterization with high frequency currents has not proven very effective.

Obstruction of the nostrils due to distortion of the septum or narrowing of the alar cartilages and the collapse of the

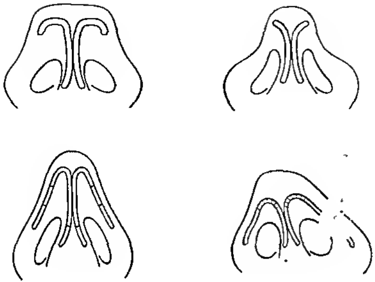

Fig. 83. Defects of the nasal cartilages about the nostrils.

ala as a result of cartilaginous deficiencies or malformations, are dealt with surgically.

A few such defects are admirably pictured in the accompanying illustrations from Converse, with the author's kind permission.[1]

CORRECTION OF THE SEPTUM. The submucous resection of the nasal septum is probably the most useful single procedure in the restoration of nasal function. Septal deviations are apt to influence any part of the nasal fossa by pressure, by over- or under-ventilation or by the maldistribution of inspired air. A portion of the nasopharynx deprived of ventilation by a septal deflection may be so reduced in its resistance to infection as to keep the patient constantly uncomfortable or in ill

1. Converse, John M.: Corrective Surgery of the Nasal Tip. Ann. of Otol., Rhin. and Laryng., 49:895 (Dec.), 1940.

health. A eustachian orifice, either deprived of air or treated to an excess of it, may be the means of setting up a low-grade tubal infection, producing tinnitus or impairing hearing. A septal bulge, impacted against a middle turbinate, may shut off the anterior series of sinuses and keep them infected. A septal spur may bear in such a way upon a branch of the spheno-palatine ganglion as to cause headaches.

In correcting deflections of the septum, it is sometimes necessary to correct other structures as well which have either been crowded or have undergone a compensatory hypertrophy as a result of the septal abnormality.

There are those who insist upon the complete operation being done on all occasions even though the deflection is confined to a small portion of the septum. However if one is skillful enough to restore the offending part without disturbing the rest, this would seem to be the logical course.

THE TURBINATED BONES. What has been said of the septum is true also of the turbinated bones, with the qualification that the erectile propensity of the latter together with their great abundance of glands renders them more important in the matter of heating and humidification. For this reason it is desirable that they be retained as far as practical in their normal positions and with their surfaces intact.

Inspired air is not directed to any great extent by the anterior margin of the middle turbinate and those portions which can obstruct the naso-frontal duct may be removed to advantage without setting up any troublesome eddies. The middle and posterior portions of this concha can not be sacrificed without causing such disturbances. It is therefore preferable, in gaining access to the sphenoid, to crowd aside this portion of the turbinate rather than to remove it.

Removal of the inferior turbinate lays open a wide tunnel direct from nostril to choana. So dire are the results of this removal that no trained rhinologist would undertake it except for the eradication of malignancy. These unfortunate results include a metaplasia of the membrane of the contiguous parts and the pharynx, low-grade infection with crusting, pharyngitis sicca and sometimes laryngitis sicca and, not infrequently, tubal hyperplasia.

When this body becomes unmanageably obstructive, it must be dealt with through some form of subtotal amputation or cautery.

Aside from physiological reasons for conserving as much of the middle turbinate as possible, there is always the danger of opening and infecting the olfactory sheaths with a resulting meningitis.[2]

CILIA. It has been shown that the cilia are surprisingly hardy. The regeneration of surface layers is a matter of hours, or at most days.

Regeneration can occur even when all the mucosal layers are stripped from the bone. Vigorously functioning ciliated epithelium is present even in chronic purulent sinusitis, and while it does not necessarily occur everywhere, even the worst-infected tunica may be covered with normally active ciliated epithelium. Very cold air may retard ciliary motion temporarily, but unless they are actually frozen the cilia will respond with increased activity on warming. Likewise, their tolerance to heat equals that of any other protoplasmic structure.

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2. Pratt, John A.: Present Status of Intranasal Ethmoid Operation. Arch Otolaryng., 1:42 (Jan.), 1925.

SINUS SURGERY. If the sinus of a dog or a rabbit is opened so that part of the respired air passes through the sinus, ciliary activity does not survive longer than a few minutes. This is of the utmost importance in planning surgical procedures.

To conserve function one must not damage this cleansing mechanism unnecessarily. Certain and permanent destruction of the cilia follows the wide opening of a sinus when this is done in such a location as to direct the nasal stream of air against a sinus wall unprepared to deal with it. Such an opening establishes a condition comparable to that of the over-ventilated side in Hilding's dogs and rabbits, and renders the sinus forever incapable of cleansing itself. Whatever mucus the membrane manages to produce is so thickened by evaporation that it is not moved by the cilia, and maintains a condition favorable to bacterial growth. If these bacteria are toxic, there is trouble. If the surface is relatively protected from direct air currents there is more or less fluid mucopus; if exposed, there is crusting.

Attempts at sinus obliteration fall into one of three groups:

The first, in which the walls are allowed to collapse and remain in contact with one another, is the only true obliteration. It is achieved only in the more disfiguring frontal sinus operations.

The second group, in which the cavity is permitted to fill with granulations, is successful when it actually obliterates. If the filling is complete and orderly all is well. If there are pockets these are bound to be infected and to remain so, as the equipment for spontaneous cleansing is lacking.

The third group is that in which one or two walls of the cavity are removed, as exemplified principally by the exentera-

tion of sphenoid and ethmoid cells. It succeeds at best in removing one or two sides of a six-sided rhomboidal cavity, exposing the remaining walls to the respired air, and depriving them of cilia.

It is not improbable that in countries such as England where the relative humidity is high, greater liberties may be taken in opening sinuses than in parts of America where extremes of climate are often accompanied by low natural humidity, and there is excessive indoor heating.

Before attempting to formulate any operative principle, may one insist that no principle should be advanced as inviolable? It is axiomatic that conditions arise to which no conservative measure is applicable, conditions comparable to those which, in other fields, require removal or amputation. This, however, does not lessen the necessity for the utmost conservation of function whenever possible, and to one's own way of thinking the skill of the rhinologist is directly proportional to his ability to accomplish this. The author has had the opportunity of observing many patients who have undergone all manner of unsuccessful sinus operations. These people come in whenever the weather changes. It is apparent that those whose sphenoidal sinuses have been widely opened are subject to constant discomfort which the slightest respiratory infection whips into active pain. Many of them have had more than one operation in what seems to have been a misguided attempt to eradicate some remote, undiscovered, infected cell. Into their sinuses, unprovided with the glands to cope with it, cold, dry and dusty inspired air is projected with each inspiration. Their squamous-cell linings are in a constant state of irritation, and so are they.

Ostia. The ostium is an important spot in the continuity of the ciliary mechanism. Since all streaming from within the sinus eventually reaches its borders and passes through its narrow confines into the nose, it is essential that it be kept in good working condition. It has already been pointed out that the ostium is in every instance well protected from the irritation of the inspired air. The area within the sinus immediately surrounding it is liberally supplied with glands, so that the mucous coat shall be continuous and maintain its normal moisture.

It will readily be seen that any functional mishap at the ostium must impair the health of the sinus. To regard it simply as an opening into the sinus, which can be roughly handled and even enlarged with impunity is to court failure in establishing hygiene of the region. Merely to make an opening is not enough. If that opening is rimmed with scars and is so exposed to the air currents as to dry the neighboring cilia, it can no longer subserve the function for which it was intended. Even if no infection persists, the mucus streams pile up and the patient is obliged to take part in a cleansing process which should be spontaneous and automatic. Nature attempts to close unphysiologic openings but unfortunately for the nose these attempts are often met with punch forceps.

Wright takes many occasions to point out the ability of the nasal mucosa to deal with its infections even after prolonged suppurative processes have made inroads into it and to function once more to all intents and purposes in a normal manner. He dates the general revulsion against operative radicalism from the publication of a brochure of Uffenorde[3] in 1907 which declared that every conservative method was fruitless

3. Uffenorde: Die Erkränkungen des Siebbeins. Jena, 1907.

and even harmful. It began to be realized that in the radical operations pus persisted in a very large number of cases, that they did not accomplish the desired ends and "that the imperfect results attendant on less radical methods at first, were not always due to conservatism."

FOUR FUNDAMENTAL PRINCIPLES. The sinuses require operative procedures compatible with their individual needs. These may be anything from slight perforation to radical extirpation. A few fundamental principles may be laid down which have their roots in physiological processes and apply to any sinus surgery.

The first principle is to retain the sinus as a functioning mechanism whenever it is at all possible.

The second is a corollary to the first, namely, to preserve the ostium untouched if it can be done.

The third is to endeavor to place any necessary opening in such a location that it will not direct air streams into the body of the cavity.

The fourth is to remove septal and turbinal tissues in such a way as not to direct air streams against ostia.

When radical surgery is required these four desiderata can be better obtained through an external than an internal approach.

THE ANNULAR CICATRIX. By keeping away from the ostium as a means of entrance one avoids converting it into an annular cicatrix.

The annular cicatrix is one of the most troublesome things in surgery, whether it be found in the naso-frontal duct or the choana, the esophagus, the urethra or any other tubular

viscus. The more ardently one strives to keep such a passage open, the more surely it closes. Therefore, since the ostium is to be preserved as a functioning gateway, common sense suggests that we establish our annular scars elsewhere.

This practice is already standard in the case of the maxillary sinus. Accessibility originally dictated that openings be made either through the inferior meatus or through the canine fossa, but the incidental retention of a functioning ostium has been one of the determining factors in the high percentage of successful results in antrum surgery.

A Sphenoid Operation. Corresponding measures have been adopted in the sphenoid with gratifying results. For the past few years the author, instead of using the sphenoid ostium as a starting point and laying bare as much of the interior as safety permitted, has made a vertical incision close to the midline or as close to the intersinal septum as possible. This has been converted with the smallest obtainable sharp biting punch into a long, narrow, vertical opening with clean-cut margins. Punching instead of tearing this opening permits the edges to heal with the smallest amount of granulation and minimizes the ultimate contraction.[4]

Through this opening anything can be done which a larger opening would permit: inspection, ventilation, drainage, irrigation. This slender mesial opening has two distinct advantages over the large one. It does not embarrass the ostium, and it does not admit a stream of air sufficient to incapacitate the cilia.

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4. Proetz, A. W.: Nasal Physiology and Its Relation to the Surgery of the Accessory Nasal Sinuses. Proc. Roy. Soc. of Med. Jour. of Laryng. and Otol., 31:1408, 1938.

Removal of the face of the sphenoid destroys at once two temperature buffers: the turbinate and the sphenoid face. The ill effects which may follow such an operation are not theoretical, and the task of restoring function in such a nose is hopeless. It should not be inferred from this that the author unqualifiedly condemns the removal of turbinates and the wide drainage of sphenoids, or that he does not perform them in selected cases.

The following accounts of experimental work are introduced at this point, as they have a direct bearing upon the rationale of nasal surgery.

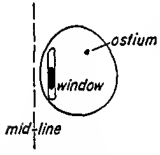

Fig. 84. Diagram of the author's sphenoid window.

Hilding removed the intersinal septum from between the frontal sinuses of the dog and stripped the membrane from more or less restricted areas. He found that the removal of strips of mucosa from concave surfaces resulted in high ridges and diaphragms of scar tissue. These interfered considerably with normal drainage causing the mucus to collect in pools. On removing a complete ring of mucous membrane from the sinus in any plane dividing the remaining mucosa into halves the circular scar sometimes produced a complete diaphragm of connective tissues, dividing the sinus into two cavities. The cavity which was shut off from nasal drainage became filled with mucin. Whether the opening in the intersinal septum remained patent or not apparently depended entirely on the surgeon's disposal of the membrane adjacent to the denuded bone. When the edges of the mucous membrane on the two sides of the opening were approximated

so as to cover the bone, the opening remained patent. If a bare strip of bone was allowed to remain, a diaphragm formed, which usually closed the opening completely. He found also that the ostium can be closed by removing a circular strip of mucous membrane from around it.[5]

ETHMOIDAL SINUSES. The ethmoidal sinuses are a problem unto themselves. Their ostia are not easily found to be avoided but on the other hand they do not lie in the direct line of the inspired air currents. When this bony honeycomb becomes converted by infection into a crowded mass of hyperplastic membrane, pus and edema nothing is to be done but a complete evacuation.

Where such an extensive blockade does not exist however there is still something to be gained by uncapping as many of the cells as possible without attempting the futile task of removing every infected bit. A moist cell with a small opening has a better opportunity of emptying itself of its contents than a dry one with a large opening.

GENERAL CONSIDERATIONS. Kistner[6] wrote in 1931 that "the mucous membrane of the paranasal sinuses has a definite characteristic architecture. Even when modified by pathologic changes, it retains all of its structural elements. It should not be confused with nasal mucosa. The sinus and nasal mucous membranes differ greatly in histologic structure, organization and appearance. After complete destruction, the sinus mucous membrane does not regenerate its structures; instead there is a process of repair and bone proliferation.

5. Hilding, Anderson: Experimental Surgery of the Nose and Sinuses. I. Arch. of Otolaryng., 16:9-18 (July), 1932. II. Arch. of Otolaryng., 17:321-327 (Mar.), 1933.

6. Kistner, F. B.: Histopathology and Bacteriology of Sinusitis with Comment on Postoperative Repair. Arch. Otolaryng., 13:225-237 (Feb.), 1931.

The walls of the cavity are lined by a layer of granulation tissue, variable in thickness, which eventually organizes and forms typical scar tissue. This becomes covered by an epithelium of variable character, determined by its place of origin and influenced by its distance from the ancestral epithelium."

However, most clinicians as well as experimenters are of the opinion that proper ciliated columnar epithelium can and often does regenerate following a radical extirpation.[7] This may remove one great objection to radical sinus surgery, on the basis that the new membrane should be better able to cleanse itself than the old hyperplastic one.[8]

When the sinus remains infected in spite of an actively draining ciliated surface, one must agree with Fenton[9] that the deeper (reticulo-endothelial) structures are at fault, and that in the plan of attack the effect of treatment (including surgical treatment) on these structures becomes the central issue.

Semenov showed that in a series of more than a thousand sections of sinus mucosa a thickening in excess of 2 mm. was often associated with deep degenerative changes.

7. Gorham, C. B., and Bacher, J. A.: Regeneration of the Human Maxillary Antral Lining. Arch. Otolaryng., 11:763 (June), 1930.—Knowlton, C. D., and McGregor, G. W.: How and When the Mucous Membrane of the Maxillary Sinus Regenerates: An Experimental Study in the Dog. Arch. Otolaryng., 8:647 (Dec.), 1928.—Matwejew, D. N.: Das Regenerationsvermögen der Nasenschleimhaut nach operativen Eingriffen. Monatschr. f. Ohrenh., 63:1293 (Dec.), 1929.—Semenov, Herman, and Kistner, F. B.: Repair in the Paranasal Sinuses of Man Following Removal of the Mucous Membrane Lining. Proc. Soc. Exper. Biol. & Med., 27:322 (Jan.), 1930.

8. Semenov, H.: The Surgical Pathology of Nasal Sinusitis. J. A. M. A., 111:2189 (Dec. 10), 1938.

9. Fenton, R. A.: Immunity in Otolaryngology. Tr. Am. Laryng., Rhin. & Otol. Soc., 37:426, 1931; Ann. Otol., Rhin. and Laryng., 40:1 (March), 1931; Mucosal Immunity in the Nose and Accessory Sinuses. Tr. Am. Laryng. Assn., 1932, p. 139; Ann. Otol., Rhin and Laryng., 41:705 (Sept.), 1932.

Whether actual devitalization of teeth occurs following external maxillary surgery, even though anesthesia results, is questionable. It has been stated on good authority that the vascular supply and hence nutrition is unimpaired.[10]

Burnham points out that three large, bony canals, carrying blood vessels, are found in the posterior three-fifths of the inferior turbinated bone and that surgical removal of this part of the bone may result in serious vascular embarrassment and congestion.

He adds that the canals are so placed that considerable narrowing occurs at their entrance to the central one-fifth of the turbinate, which under certain circumstances may constitute enough of a bottle-neck to maintain a protracted intumescence.[11]

Surgical measures which direct the main body of the air stream against the roof of the nose are to be avoided wherever possible first because they may result in intractable headaches and second because any undue drying of the olfactory area may produce a parosmia or even an anosmia.

* * *

10 Strong, Cecil: The Innervation and Vascular Supply of the Antrum. J. Laryng. and Otol., 49:400 (June), 1934.

11. Burnham, Howard H.: An Anatomical Investigation of Blood Vessels of the Lateral Nasal Wall and Their Relation to Turbinates and Sinuses. Jour. of Laryng and Otol., 50:569 (Aug.), 1935.

It should be repeated in closing that with the exception of those references specifically named, the last two chapters represent no more than the author's own deductions based upon experience and the physiological processes of the nose as he understands them. The student will do well, therefore, to begin by familiarizing himself first with these processes, and later to accept the author's conclusions only until his ripening experience permits him to supplant them with his own.

APPENDIX

The few experiments which follow are suggested to accompany a course of lectures in order to afford the student an opportunity of observing some of the more elemental phenomena for himself and possibly to stimulate him in undertaking investigations of his own. Most of them are simple and require little time or equipment. Some necessitate preparation on the part of the instructor.

Anyone desiring to plan a complete laboratory course in nasal physiology will do well to consult the references given in the footnotes to the text, not a few of which relate to experimental methods.

(CHAPTER IV)

EXPERIMENT 1: *Determination of the Minimum Perceptible.*—Procure ten wide-mouthed glass-stoppered 50 c.c. bottles (or 2-ounce bottles), cleanse them and rinse thoroughly in hot water. Dry.

Weigh accurately about 1 gm xylol: make up to 500 c.c. with liquid petrolatum (Sp. G. .880) and use this as a stock solution. Keep a record of the amount of xylol in the solution, in grams per litre.

Measure 50 cc. into the first bottle. Withdraw 25 cc. transfer this to the second bottle and make up to 50 c.c. with petrolatum. Stir well.

Withdraw 25 cc. of this dilution and transfer to the third bottle. In this manner continue successive dilutions reducing the concentration each time by ½ until each of the ten bottles contains 25 c.c. of a known solution, each solution ½ the strength of the preceding. Proceed by testing subjects with these solutions as described on page 101 to determine the minimum perceptible.

EXPERIMENT 2: *Distinction of Odors.*—Into small, clean, wide-mouthed bottles place a few cc. of the following ten substances:

oil of lavender	alcohol
oil of cloves	benzene
oil of bitter almond	thymol
oil of orange peel	turpentine
oil of wintergreen	extract of vanilla

Do not label. Permit the students to identify by smelling them. Note 1) the innate difficulty in distinguishing them, and 2) the ease with which one can learn to do so.

EXPERIMENT 3: *Fractional Fatigue.*—Half fill two similar wide-mouthed bottles with a 20% solution of oil of peppermint in petrolatum. To the first add a drop or two of oil of anise from the tip of a stirring rod and mix thoroughly. Unless the bottles are very small the anise will not be detected and the two bottles will be indistinguishable by the sense of smell. Continue adding traces of anise to the first bottle until its faint odor mingled with the peppermint distinguishes it from its fellow.

Now fill the two bottles with the 20% peppermint solution.

The room should now be aired, or the bottles removed to another place. Ten minutes later the student should begin the experiment of attempting to identify the anise-contaminated bottle. If he can do so at once there is too much anise present. If not he should apply his nose to the pure peppermint odor for 5 minutes. At the end of this time he will probably be able to distinguish the two solutions. This fatigue phenomenon is variable with time and persons, and accurate quantities of the two oils can therefore not be given.

EXPERIMENT 4: *Importance of Distribution.*—Hold the breath, and insure against any air currents passing through the nose by pressing the lips together and forcing the column of air from the chest against the tightly closed velum palati, as though preparing to blow a trumpet. Strongly odorous substances may now be brought close to the nose without being detected by the subject, although their odor may perme-

ate the room if they are left uncorked. A slight sniffing is required to record smell impressions.

EXPERIMENT 5: *Odorous Solutions.*—To a few ounces of a physiological sodium chlorid solution add spirits eau de cologne drop by drop until the mixture is definitely scented.

Place the student supine upon a table and allow his head to hang over the edge, with his chin in a vertical plane above his external auditory meatuses.

Fill his nose with the solution. Although it obviously reaches his olfactory area he will not detect the odor. There may be some tingling through stimulation of the sensory nerve endings.

(CHAPTER V)

For the experiments in this group it will be necessary to construct a model of glass and rubber to represent the mechanical relationships of the nasal cavity and an accessory sinus. Obtain a piece of glass tubing approximately 2½ cm. in diameter and 8 cm. in length. Close one end with a rubber stopper which fits closely.


Fig. 85.

Select a second rubber stopper which exactly fits the inside diameter of the tube, cut a slice from it about ½ cm. thick and make a small hole through the center. Push this perforated disc into the tube until it forms a partition 2 cm. from the stoppered end. Fit into the remaining end a rubber disc similar to the first but having a relatively large hole in the center. Fig. 85 represents a section of this apparatus. It is important that the three rubber discs all fit the tube snugly.

The small chamber in this model represents the sinus; the small opening in the partition, the ostium. The large chamber represents the nasal fossa; the large opening, the nostril. The walls of these chambers are all rigid as are the walls of the nose and the accessory sinuses. The only elastic element is the contained air.

Draw out one end of a short length of glass tubing to make a pipette. The drawn out portion should be sufficiently long and narrow to pass through both the "nostril" and the "ostium" and reach into the "sinus".

EXPERIMENT 6: *Effect of Generalized Suction.*—By means of the pipette gently blow smoke from a cigarette into the "sinus". This should be done so slowly that the chamber fills with dense smoke and the "fossa" is free from it.

Attach an olive-tipped suction tube to any type of clinical suction apparatus and apply it to the "nostril". The negative pressure should be not more than 150 mm. Hg., a pressure which is safe in the nose. Note the exchange of air between the two chambers through the "ostium" as the pressure is reduced and allowed to return to normal (cf. p. 110).

EXPERIMENT 7: *Effect of Suction by Means of a Cannula.*—Again fill the "sinus" with smoke. This time substitute a thin nasal cannula for the olive tip, pass it into the "sinus" and apply suction until the smoke is removed. Compare this procedure with the last.

EXPERIMENT 8: *Effect of Generalized Suction in the Small Sinuses.*—By means of the pipette introduce water into the smaller chamber until it is half full or move the partition to within one cm. of the stopper. The elastic element (air) is now reduced to one-half its former volume. Again introduce smoke into this chamber, now one-half its former size, and repeat Experiment 6. Note that less smoke is withdrawn with each application of the olive tip but that proportionally the amount is the same provided the negative pressure remains the same.

EXPERIMENT 9: *Nasal Suction when a Sinus is Full.*—Fill the small chamber with water. Apply the suction tip to the large chamber and note that when the "sinus" is completely full none of the fluid can be made to escape by applying negative pressure.

Now remove approximately one-fourth of the water from the small chamber through the pipette and place the apparatus in a horizontal position. Apply suction to the "nostril" intermittently. Note that now

small quantities of water escape through the "ostium", since the elastic element has been introduced into the system. Note also that once the fluid falls to the level of the "ostium" no further fluid can be removed by suction.

EXPERIMENT 10: *Extent of Filling a Closed Chamber With One Orifice.*—Lay the empty apparatus in a horizontal position so that the "ostium" is half way up the side of the wall. Attempt to fill the "sinus" with a cannula, by intermittent suction (displacement), or by any other means. Note that so long as there is only one orifice the chamber cannot be filled above its level. In order to fill the chamber completely the orifice must be at the top.

EXPERIMENT 11: *Effect of Accessory Ostia.*—Replace the middle stopper with one having two small openings and repeat Experiments 6 and 7. Note that the mechanics of the system remain practically unchanged in the presence of the accessory ostium (cf. Fig. 30, p. 111).

(CHAPTER VI)

EXPERIMENT 12: *Air Currents.*—Cut strips of blue litmus paper 3 mm. by 2 cm. Moisten them. Select a subject whose septum is relatively free from ridges and deviations and apply a strip of the litmus paper vertically to each side of the septum midway between the nostril and the choana.

Observing the precautions detailed on Page 124, perform the experiment as there described. Note that in both inspiration and expiration the litmus colors first at the top of the strip.

EXPERIMENT 13: *Air Currents in the Nose.*—Obtain two sheets of plate glass 30 cm. x 40 cm. and have ¼-inch holes drilled near the four corners of each plate, by which they can be bolted together. Four slim bolts 6 cm. long should be used for this purpose.

Next obtain the head of a cadaver in which the tissues have not shriveled during the preserving process. With a band saw separate it into the two halves, making the cut as nearly in the midline as possi-

ble. The septum will usually be found on one half or the other, being not quite in the midline itself. Select the half without the septum and cut it again parallel to the first cut and 4 cm. lateral to it.

Fit the end of a two-foot length of half-inch rubber tubing into the trachea, pack the soft tissues around it, or use moist cotton if necessary, and clamp the specimen between the glass plates, distributing the pressure equally among the four bolts.

From the edge of a roll of cotton pull a continuous strip four inches wide and long enough to surround the head. Moisten it and pack it, wedging it firmly between the glass plates to make all margins air-tight. Start at the nose working over the bridge to the forehead,

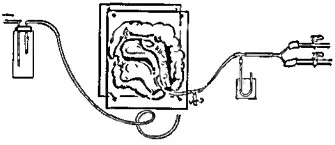

Fig. 86.

finally completely encircling the head, and end by plugging the mouth. Only the naris is now free. See that this is neither distorted nor obstructed in any way.

Connect the tube in the trachea to a manometer, thence to a Y-tube, the arms of which are connected with the laboratory air and vacuum outlets respectively.

Construct a smoke generator by fixing a cigarette holder into one hole of a two-hole stopper of a 500 cc. wide-mouthed bottle. Into the other hole insert a glass tube connected to an air outlet. The lighted cigarette hangs inverted in the bottle as shown in the figure. When air is forced through the apparatus, smoke issues from the cigarette holder. This is supplied through a half inch rubber hose to the vicinity of the nostril for inspiration or to the tracheal tube (via a

T-tube as shown in the illustration) for expiration. The stream from the smoke generator should be at about the same pressure as that in the tracheal tube. The smoke will then flow at the same rate as the air (Fig. 86).

Having placed a lighted cigarette in the holder and started the smoke stream, turn on the pet-cock in the vacuum line leading to the trachea until the water level in the manometer indicates a negative pressure of 8-10 mm. (This is more than the normal nasal pressure but approximates that at the glottis.)

Hold the end of the smoke tube near (but not against) the nostril and observe the pathways taken by the smoke and air as they traverse the nasal chamber.

It is important that the head be cut flat as minor irregularities will permit leaks and cause eddies which alter the pattern of streaming.

Note how narrow the breathing channels are.

Now shut off the vacuum pet-cock and open the one in the air-pressure line until the manometer registers 8-10 mm. positive pressure.

Connect the smoke tube to the T-joint in the line near the trachea, and observe the expiratory currents.

EXPERIMENT 14: *The Impingement Effect.*—Over a Bunsen burner bend a number of tubes and draw them out as shown in Fig. 37, p. 130. Blow a mouthful of cigarette smoke through a straight tube of even diameter against a white card. Unless unusual pressure is applied the card will remain white.

Now draw out the tube to a capillary tip and repeat. This time a brown deposit of tar collects on the card.

Blow smoke through the other tubes. The effect of the impingement can be noted as shown in the figure. If the smoke currents are slow it requires somewhat longer to detect the deposits. If they are rapid they appear promptly. The location is the same in either case. .

EXPERIMENT 15: *Effect of Ventilation on the Mucosa.*—Under general anesthesia and with all possible asepsis make a circular in-

cision about one nostril of a rabbit and after elevating the edges, close the nostril by sewing the tissues layer to layer. Maintain the rabbit under the best conditions of nutrition and environment. After an interval of 120 days, kill it and remove the septum. From this prepare stained sections, being careful to retain the mucosa on both sides of the cartilage, and make a comparative microscopic study of the two sides.

EXPERIMENT 16: *Currents Through the Ostium.*—Again fill the small chamber of the model employed in Exp. 6 with smoke. Hold the other end of the tube in the mouth, making a tight contact between the glass and the lips. Breathe naturally through the nose. In this way positive and negative pressures will be set up in the mouth similar to those in the nose, which will be transmitted to the "nasal fossa" of the model. With the smoke as an indicator the effect of fluctuating pressures at the "ostium" can be studied.

(CHAPTER VII)

For the following experiments twin manometers will be required, which may be simply prepared as follows:

Bend two glass tubes over a Bunsen burner (with a yellow flame) as shown in Fig. 87. It will be of advantage in supporting the tubes and in comparing the fluid levels if one is curved to fit within the other as shown in the illustration.

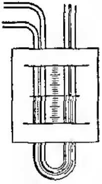

Fig. 87.

Draw upon a stiff card a column of 1 mm. graduations such as those shown in Fig. 88 and cut two slits in it as indicated by the dashed lines. Slip this card over the tubes as shown. Support the instrument by means of some type of laboratory clamp. Through a pipette drawn out to a fine point introduce water, preferably stained with a drop of ink, into each of the tubes so that it reaches the same level about midway in both tubes. Slide the card up or down until the zero-line of the graduations coincides with the fluid level. It should be remembered in taking the readings that pressure devi-

ations in mm. H_2O equal the sum of the deviations in the right and left arms of the tube, or double that of either one.

EXPERIMENT 17: *Pressures in the Nose and the Sinuses.*—Prepare two similar antrum puncture trocars and two similar pieces of rubber tubing with which to connect them to the manometers. When the occasion arises for the perforation of a maxillary sinus in the clinic, perform it with one of the prepared trocars which is connected to one of the manometers. While this is in place the second trocar connected to the second manometer is held in the nasal chamber so that its tip is practically opposite that of the trocar in the sinus. If the ostium is closed, pressure on the manometer will rise. For this reason it is best to attach the tube to the trocar after latter has been inserted, by means of a bayonet joint. Study the nature of the fluctuation in each of the two manometers and compare them (cf. p. 143-145).

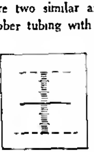

Fig. 88.

EXPERIMENT 18: *Effect of the Relative Sizes of Nostril and Choana.*—Obtain a piece of 2½ cm. glass tubing similar to that used in Experiment 6, but with a small outlet in the middle of one side (cf. Fig. 89). Connect this outlet through a flexible tube to a manometer. It represents the ostium of a sinus. Now obtain three rubber stoppers, one of them having a small perforation, the other two having larger perforations, twice the diameter of the first.

Fig. 89.

I) Into one end fit the stopper with the small opening, into the other fit one of the stoppers with a large opening. Holding the latter end of the tube in the mouth, breathe through it as naturally as possible (closing the nose) and observe the fluctuations of the fluid in the manometer. This system approximates conditions shown in A, p. 138.

II) Without changing the stoppers reverse the tube and breathe into it holding the other end in the mouth and note the fluctuations of the fluid in the manometer. The system now approximates C, p. 138.

III) Now remove the stopper with the small perforation and replace it with one having a large perforation. The openings on opposite ends of the tube are now of the same size and the system approximates conditions shown in B, p. 138. Again compare the fluctuations of the fluid in the manometer.

(CHAPTER IX)

EXPERIMENT 19: *Relative Humidity.*—Obtain a pair of wet- and dry-bulb thermometers preferably in the form of a sling psychrometer.

a) Take a reading outdoors and record the relative humidity.

b) Take a reading indoors (in a small room) and record the relative humidity.

c) Place a vessel containing a measured amount of water on a heater and allow it to boil away. At regular intervals record the amount of water evaporated, and record the temperature and the relative humidity of the room.

d) Make a note of the amount of moisture which may condense on the window panes.

EXPERIMENT 20: *Glatzel's Mirror.*—Obtain a small plate of highly polished metal—a small metal "trench mirror" is ideal.

Immerse it in water at 20° C. Remove it and dry quickly between blotters. Breathe upon it one full breath holding it against the upper lip perpendicular to the jets of air from the nostrils.

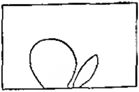

Fig. 90.

Note the size and shape of the areas of condensation, mark the outlines with a china marking pencil, and time with a stop-watch the number of second required for the moisture from each nostril to disappear.

Repeat the experiment this time immersing the plate first in water at 30° C. Again in water at 40° C.

Trace the patterns and record the findings for reference.

If one area is larger and of a different shape than the other, mark the difference in evaporating time.

Now with the plate at any one of the above temperatures hold one nostril shut without distorting the other and repeat the experiment breathing on one side alone and exhaling the full breath as before. Record the findings.

Take a short length of glass tubing, hold it perpendicular to the surface of the plate and 1 cm. away from it and blow through the tube for 5 measured seconds. Record the data: size, shape, duration.

Repeat, applying the air stream for 10 measured seconds, and exercising great care to maintain all the other conditions as before. Record the data and compare the results.

Still maintaining the temperature repeat the two foregoing experiments with the tube this time at an angle of 45° to the plate, the tip still 1 cm. away from it. Record the data and compare with the preceding.

From these condensation experiments it will be evident that there are several factors influencing the pattern: shape of the nozzle, area exposed temperature of the plate, direction of the stream; also that the evaporation time varies in inverse ratio to the area. To one conversant with it the Glatzel mirror can be clinically useful. To another it can easily be misleading.

(CHAPTER X)

EXPERIMENT 21: *Nasal Temperature.*—For the following experiments a small thermopile is desirable, but lacking this a clinical thermometer will answer.

a) Place the tip of the thermopile or the bulb of the thermometer in various locations in the nasal fossa and measure the maximum nasal temperature attained during nasal breathing. (The thermopile will record fluctuations between inspiration and expiration, the clinical thermometer will record only the maximum temperature.)

b) Repeat the experiment closing both nostrils and breathing only through the mouth.

c) Repeat the experiment inhaling only through the nose and exhaling only through the mouth.

d) Repeat the experiment exhaling only through the nose and inhaling only through the mouth (cf. p. 170).

EXPERIMENT 22: *Nasal Temperatures.*—Apply hot compresses to the forehead, nose and cheeks and repeat the foregoing, recording temperatures at the beginning of the experiment and at two minute intervals for ten minutes.

(CHAPTER XI)

EXPERIMENT 23: *Surface Charges.*—Obtain two flat pieces of tin or other metal approximately 10 cm. x 15 cm. in size. Make saw-cuts into two small blocks of any insulating substance, such as bakelite and use them to support one of the metal plates vertically above the other which is lying horizontally as shown in Fig. 91. The plates should be separated from one another by about 1 cm.

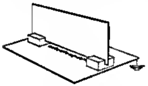

Fig. 91.

Scatter some flakes of cigarette ash loosely upon the horizontal plate beneath the edge of the vertical plate but not touching it.

Ground the horizontal plate by connecting it electrically to some convenient water pipe.

Walk about the room making friction between the shoes and the carpet until a moderate surface charge is built up on the body surface. On touching the vertical plate the cigarette ash will jump up and cling to its lower edge, where it will remain until the two plates return to nearly the same potential.

It goes without saying that a charge of this magnitude can be built up only in winter when the atmosphere is dry. Shoes, carpet and

clothing must all be perfectly dry—conditions under which one ordinarily draws sparks from metal objects.

It will be noted that at the end of the experiment charged fibers from the carpet will be found clinging to the shoes.

EXPERIMENT 24: *Surface Charges.*—If a galvanometer or a portable electro-cardiograph is available fluctuations in these charges can be observed.

Ground one pole of the instrument. To the other connect an electrode in contact with the body surface, or the nasal mucosa. As the subject moves about the room charges will be recorded by the instrument (cf. p. 177).

(CHAPTER XII)

Material for the following experiments may be obtained from the noses and tracheas of rabbits or guinea pigs or from the surface of some adenoids removed at operation. The former is the more satisfactory.

EXPERIMENT 25: *Cilia—Profile View.*—From the stock specimen of mucosa which is kept in Ringer's solution, cut the smallest piece obtainable. This is best done with small, pointed, curved manicure scissors. Larger specimens have a tendency to curl. Place the specimen on a microscope slide and cover with Ringer's solution. Manipulate it with a dissecting needle until a good profile view is obtained (cf. p. 189). Compare this with a stained specimen (cf. p. 188).

EXPERIMENT 26: *Cilia—Vertical View.*—For this purpose the whole specimen is laid upon the slide or upon a metal plate and the light is projected from the side through a condensing lens and a cooling chamber. The combination of a low-power objective with a high-power ocular is recommended in order to afford a maximum depth of field. It is necessary to focus upon a ridge in the specimen which catches the light and reflects it into the lens. As the specimen is kept wet either by means of a double capillary tube or a pipette the cilia cannot be seen. Therefore it is necessary, after all adjustments have

been made, to allow the specimen to dry somewhat. As this progresses wave motion makes its appearance and finally the cilia themselves can be seen. Moisture must be supplied shortly after or movement will cease. As this moisture drains off, or evaporates, motion will reappear.

Opaque illuminators are convenient for this experiment but not essential.

(CHAPTER XIII)

EXPERIMENT 27: *Cilia—Streaming.*—Using the above apparatus, place a fragment of nasal mucosa about ½ cm. square, removed from the nose of a rabbit and still attached to the underlying cartilage or bone, on the stage of the microscope. Blow a few granules of lamp black onto the surface and watch their progress across the field.

This can be better observed upon a specimen recently removed as suggested, than upon one from which the mucus has been washed away.

EXPERIMENT 28: *The Mucous Blanket.*—When the carbon granules in the above experiment have been found to be in motion it is sometimes possible to restrain the mucus coat at one side of the field by means of a bristle or the edge of a fragment of cover glass in such a manner that strains in the moving blanket can be demonstrated (cf. p. 202).

EXPERIMENT 29: *Pathways.*—Under general anesthesia open the sinus of a dog or a rabbit and deposit a minute amount of Chinese ink upon the surface of the mucosa. Protect the sinus from air currents by covering the surgical opening with a glass slide or a watch crystal and note the patterns of streaming (cf. p. 211).

For this purpose aqueous solutions of stick ink should be used, as some of the prepared inks contain deleterious substances.

(CHAPTER XIV)

EXPERIMENT 30. Experiments in the regeneration of nasal mucosa in the animal, and its culture *in vitro*, while not necessarily beyond the scope of the student, require carefully controlled solutions and conditions, and considerable time.

Details can best be obtained through the references supplied in the chapter.

(CHAPTER XV)

For the following experiments the same apparatus is employed as that described under Chap. XII, Exp. 26.

Extirpated tissues are more easily handled for this purpose than parts of living animals and the results are much the same.

EXPERIMENT 31: *Local Drying.*—Having selected a suitable field with vigorous ciliary activity, allow a minute jet of air from a capillary tube to play upon a portion of it and note the behavior of the cilia in the moist portions, the partly dry portions and the dry center of the area.

EXPERIMENT 32: *Heat and Cold.*—By means of a simple apparatus such as that described on p. 224, apply cold and then heat in various degrees to the specimen and note the effect upon the ciliary activity at the different temperatures.

EXPERIMENT 33: *Effect of Drugs.*—With the apparatus as in Exp. 31 and employing the double capillary tube supported in a clamp attached to the microscope, as shown in Fig. 69, apply the following solutions, and note the effects. Use a fresh piece of tissue in each case.

Ephedrin sulphate in Ringer's solution, ½%, 2%, 3%.

Cocain hydrochlorid in Ringer's solution, 2%, 5%, 10%.

Epinephrin 1-1000 and 1-5000 in Ringer's solution.

Others *ad lib.*

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